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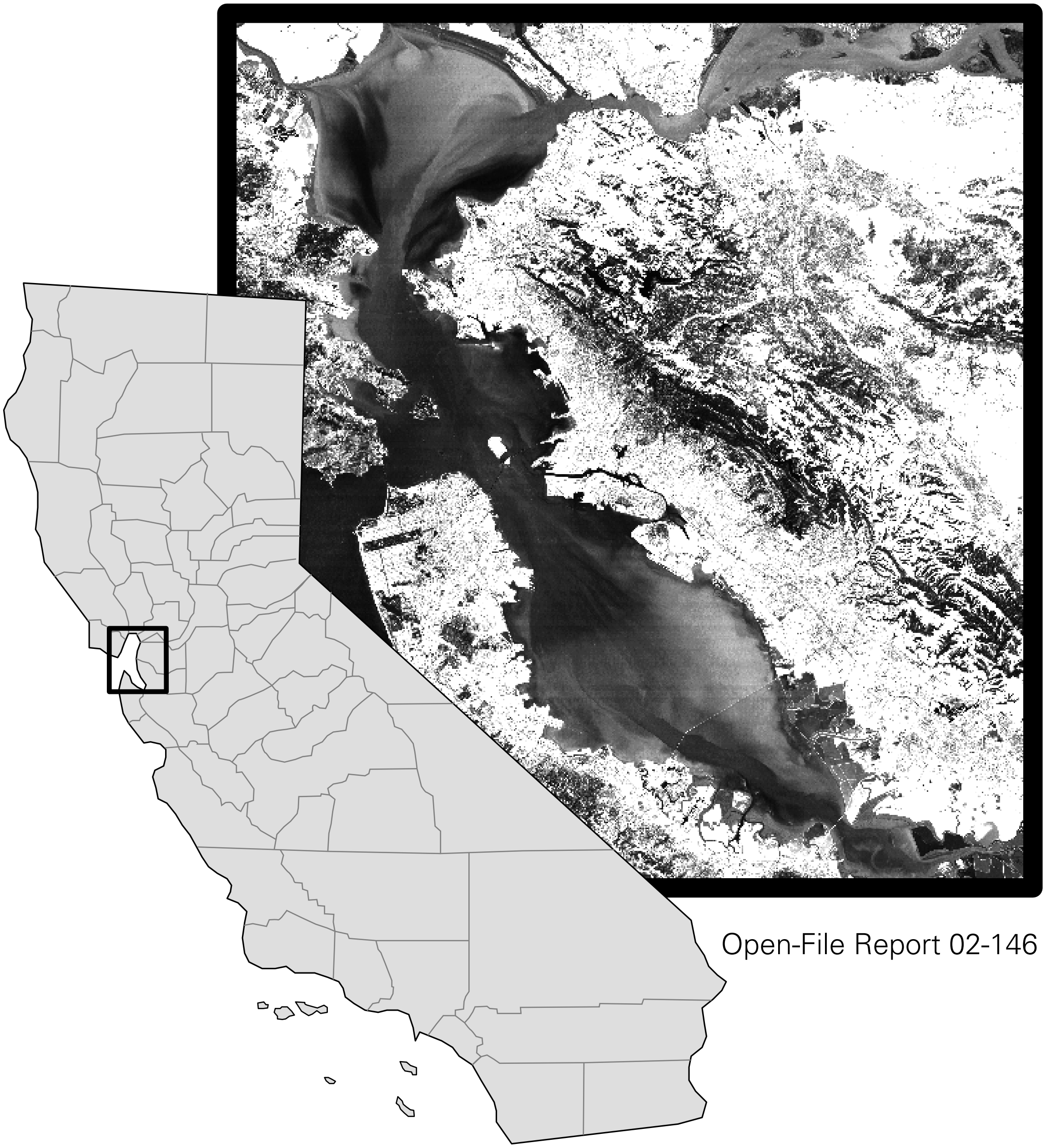
Summary of Suspended-Sediment Concentration Data, San Francisco Bay, California, Water Year 2000



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Prepared in cooperation with the CALFED BAY-DELTA PROGRAM, the
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U.S. ARMY CORPS OF ENGINEERS, San Francisco District

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By Paul A. Buchanan and Neil K. Ganju

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U.S. DEPARTMENT OF THE INTERIOR
GALE A. NORTON, Secretary

U.S. GEOLOGICAL SURVEY
Charles G. Groat, Director

For additional information write to:

District Chief
U.S. Geological Survey
Placer Hall, Suite 2012
6000 J Street
Sacramento, CA 95819-6129

Copies of this report can be purchased from:

U.S. Geological Survey
Information Services
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CONTENTS

Abstract 1
Introduction 1
  Purpose and Scope 2
  Study Area 2
  Acknowledgments 2
Methods 4
  Instrument Description and Operation 4
    Suisun Bay Installations 7
      Mallard Island 8
    San Pablo Bay Installations 8
      Carquinez Bridge 8
      Mare Island Causeway 8
      Channel Marker 9 9
    Central San Francisco Bay Installations 9
      Point San Pablo 9
      Pier 24 9
    South San Francisco Bay Installations 9
      San Mateo Bridge 9
      Dumbarton Bridge 10
      Channel Marker 17 10
  Water-Sample Collection 10
  Data Processing 11
Sensor Calibration and Suspended-Sediment Concentration Data 12
  Suisun Bay 14
    Mallard Island 14
  San Pablo Bay 17
    Carquinez Bridge 17
    Mare Island Causeway 20
    Channel Marker 9 23
  Central San Francisco Bay 26
    Point San Pablo 26
    Pier 24 29
  South San Francisco Bay 32
    San Mateo Bridge 32
    Dumbarton Bridge 10
    Channel Marker 17 10
Summary 39
References Cited 41

FIGURES

1. Map showing San Francisco Bay study area, California 3
2. Graph showing sonde turbidity sensor linearization error 5
3. Schematic showing typical monitoring installation, San Francisco Bay study 6

4–22. Graphs showing:
4. Example of raw (*A*) and edited (*B*) optical backscatterance data, mid-depth sensor, Point San Pablo, Central San Francisco Bay, water year 1994 12
5. Calibration of near-surface (*A*) and near-bottom (*B*) optical backscatterance sensors at Mallard Island, Suisun Bay, water year 2000.......... 15
6. Time series of near-surface (*A*) and near-bottom (*B*) suspended-sediment concentrations calculated from sensor readings at Mallard Island, Suisun Bay, water year 2000 16
7. Calibration of mid-depth (*A*) and near-bottom (*B*) optical backscatterance sensors at Carquinez Bridge, San Pablo Bay, water year 2000 18
8. Time series of mid-depth (*A*) and near-bottom (*B*) suspended-sediment concentrations calculated from sensor readings at Carquinez Bridge, San Pablo Bay, water year 2000 19
9. Calibration of mid-depth (*A*) and near-bottom (*B*) optical backscatterance sensors at Mare Island Causeway, San Pablo Bay, water year 2000 21
10. Time series of mid-depth (*A*) and near-bottom (*B*) suspended-sediment concentrations calculated from sensor readings at Mare Island Causeway, San Pablo Bay, water year 2000 22
11. Calibration of near-bottom optical backscatterance sensor, October 1–February 15 (*A*) and February 15–September 30 (*B*) at Channel Marker 9, San Pablo Bay, water year 2000.......... 24
12. Time series of near-bottom suspended-sediment concentrations calculated from sensor readings at Channel Marker 9, San Pablo Bay, water year 2000 25
13. Calibration of mid-depth (*A*) and near-bottom (B) optical backscatterance sensors at Point San Pablo, Central San Francisco Bay, water year 1999 27
14. Time series of mid-depth (*A*) and near-bottom (*B*) suspended-sediment concentrations calculated from sensor readings at Point San Pablo, Central San Francisco Bay, water year 2000 28
15. Calibration of mid-depth (*A*) and near-bottom (*B*) optical backscatterance sensors at Pier 24, Central San Francisco Bay, water year 2000 30
16. Time series of mid-depth (*A*) and near-bottom (*B*) suspended-sediment concentrations calculated from sensor readings at Pier 24, Central San Francisco Bay, water year 2000 31
17. Calibration of mid-depth (*A*) and near-bottom (*B*) optical backscatterance sensors at San Mateo Bridge, South San Francisco Bay, water year 2000 33
18. Time series of mid-depth (*A*) and near-bottom (*B*) suspended-sediment concentrations calculated from sensor readings at San Mateo Bridge, South San Francisco Bay, water year 2000 34
19. Calibration of mid-depth (*A*) and near-bottom (*B*) optical backscatterance sensors at Dumbarton Bridge, South San Francisco Bay, water year 2000 36
20. Time series of mid-depth (*A*) and near-bottom (*B*) suspended-sediment concentrations calculated from sensor readings at Dumbarton Bridge, South San Francisco Bay, water year 2000 37
21. Calibration of mid-depth (*A*) and near-bottom (*B*) optical backscatterance sensors at Channel Marker 17, South San Francisco Bay, water year 2000 39
22. Time series of mid-depth (*A*) and near-bottom (*B*) suspended-sediment concentrations calculated from sensor readings at Channel Marker 17, South San Francisco Bay, water year 2000 40

TABLES

1. Statistical summary of suspended-sediment concentration data, Suisun Bay, San Pablo Bay, and Central and South San Francisco Bays, water year 2000.......... 7

2. Percentage of 1 complete year of valid data (96 data points per day) collected by optical backscatterance sensors, Suisun Bay, San Pablo Bay, and Central and South San Francisco Bays, water year 2000 11

CONVERSION FACTORS, VERTICAL DATUM, ABBREVIATIONS, AND ACRONYMS

Multiply	By	To obtain
inch (in.)	25.40	millimeter
foot (ft)	.3048	meter
foot per second (ft/s)	.3048	meter per second
mile (mi)	1.609	kilometer
pound (lb)	.4536	kilogram

Temperature in degrees Celsius (˚C) may be converted to degrees Fahrenheit (˚F) as follows:

$$˚F=1.8(˚C)+32.$$

Vertical Datum

***Sea level*:** In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)—a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929.

Mean lower low water (MLLW): The average of the lower low water height of each tidal day observed over the National Tidal Datum Epoch. The National Tidal Datum Epoch is the specific 19-year period (1960-1978 for values given in this report) adopted by the National Ocean Service as the official time segment over which tide observations are taken and reduced to obtain mean values.

Abbreviations:

Ah ampere hour
mg/L milligram per liter
mV millivolt
V volt

Acronyms

AC alternating current
ADAPS automated data-processing system
DWR California Department of Water Resources
NTU Nephelometric Turbidity Units
PI_{np} nonparametric prediction interval
PVC polyvinyl chloride
RMS root mean squared
USCG U.S. Coast Guard
USGS U.S. Geological Survey

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ABSTRACT

Suspended-sediment concentration data were collected in San Francisco Bay during water year 2000 (October 1, 1999–September 30, 2000). Optical backscatterance sensors and water samples were used to monitor suspended sediment at one site in Suisun Bay, three sites in San Pablo Bay, two sites in Central San Francisco Bay, and three sites in South San Francisco Bay. Sensors were positioned at two depths at most sites. Water samples were collected periodically and were analyzed for concentrations of suspended sediment. The results of the analyses were used to calibrate the electrical output of the optical backscatterance sensors. This report presents the data-collection methods and summarizes the suspended-sediment concentration data collected from October 1999 through September 2000. Calibration plots and plots of edited data for each sensor also are presented.

INTRODUCTION

Sediments are an important component of the San Francisco Bay estuarine system. Bottom sediments provide habitat for benthic organisms and are a reservoir of nutrients that contribute to the maintenance of estuarine productivity (Hammond and others, 1985). Potentially toxic substances, such as metals and pesticides, adsorb to sediment particles (Kuwabara and others, 1989; Domagalski and Kuivila, 1993; Flegal and others, 1996). Benthic organisms can ingest these substances and introduce them into the food web (Luoma and others, 1985; Brown and Luoma, 1995; Luoma, 1996).

The transport and fate of suspended sediments are important factors in determining the transport and fate of constituents adsorbed on the sediments. In Suisun Bay, the maximum concentration of suspended sediment usually marks the position of the turbidity maximum, which is a crucial ecological region in which suspended sediments, nutrients, phytoplankton, zooplankton, larvae, and juvenile fish accumulate (Peterson and others, 1975; Arthur and Ball, 1979; Kimmerer, 1992; Jassby and Powell, 1994; Schoellhamer and Burau, 1998).

Suspended sediments limit the availability of light in San Francisco Bay, which, in turn, limits photosynthesis and primary phytosynthetic carbon production (Cole and Cloern, 1987; Cloern, 1987, 1996). Suspended sediments also deposit in ports and shipping channels, which must be dredged to maintain navigation (U.S. Environmental Protection Agency, 1992). Large tidal velocities, spring tides, and wind waves in shallow water all are capable of resuspending bottom sediments (Powell and others, 1989; Schoellhamer, 1996). The U.S. Geological Survey (USGS), in cooperation with the CALFED Bay-Delta Program, the San Francisco Regional Water Quality Control Board, and the U.S. Army Corps of Engineers, is studying the factors that affect suspended-sediment concentrations in San Francisco Bay.

Purpose and Scope

This report summarizes suspended-sediment concentration data collected by the USGS in San Francisco Bay during water year 2000 (October 1, 1999–September 30, 2000) and is the latest in a series based on data collected beginning in water year 1992 (Buchanan and Schoellhamer, 1995, 1996, 1998, 1999; Buchanan and others; 1996; Buchanan and Ruhl, 2000, 2001). Suspended-sediment concentrations were monitored at one site in Suisun Bay, three sites in San Pablo Bay, two sites in Central San Francisco Bay, and three sites in South San Francisco Bay. These data are used to determine the factors that affect suspended-sediment concentrations in San Francisco Bay (for current bibliography refer to http://ca.water.usgs.gov/abstract/sfbay/sfbaycontbib.html/). Suspended-sediment concentration data for water years 1992 through 2000 are available at the USGS California District Office in Sacramento, California.

Study Area

San Francisco Bay (fig. 1) comprises several major subembayments; Suisun Bay, San Pablo Bay, Central San Francisco Bay (Central Bay), and South San Francisco Bay (South Bay). In San Francisco Bay, tides are semidiurnal (two high and two low tides per day) with a range of about 5.5 feet (ft) in Suisun Bay, 6.5 ft at the Golden Gate and Central Bay, and about 10 ft in South Bay. The tides also have a 14-day spring-neap cycle. Typical tidal currents range from 0.6 foot per second (ft/s) in shallow water to more than 3 ft/s in deep channels (Cheng and Gartner, 1984; Smith, 1987). Winds typically are strongest in summer during afternoon onshore breezes. Most precipitation occurs from late autumn to early spring, and freshwater discharge into San Francisco Bay is greatest in the spring due to runoff from snowmelt. About 90 percent of the discharge into the Bay is from the Sacramento-San Joaquin River Delta, which drains the Central Valley of California (Smith, 1987).

Typically, discharge from the Delta contains 83–86 percent of the fluvial sediments that enter the Bay (Porterfield, 1980). During wet winters, turbid plumes of water from the Delta have extended into South Bay (Carlson and McCulloch, 1974). The bottom sediments in South Bay and in the shallow water (about 12 ft or less) of Central, San Pablo, and Suisun Bays are composed mostly of silt and clay. Silt and sand are present in the deeper parts of Central, San Pablo, and Suisun Bays and in Carquinez Strait (Conomos and Peterson, 1977).

Acknowledgments

The authors gratefully acknowledge the U.S. Coast Guard (USCG), California Department of Transportation, California Department of Water Resources (DWR), the San Francisco Port Authority, the PakTank Corporation, and the City of Vallejo for their permission and assistance in establishing the monitoring sites used in this study.

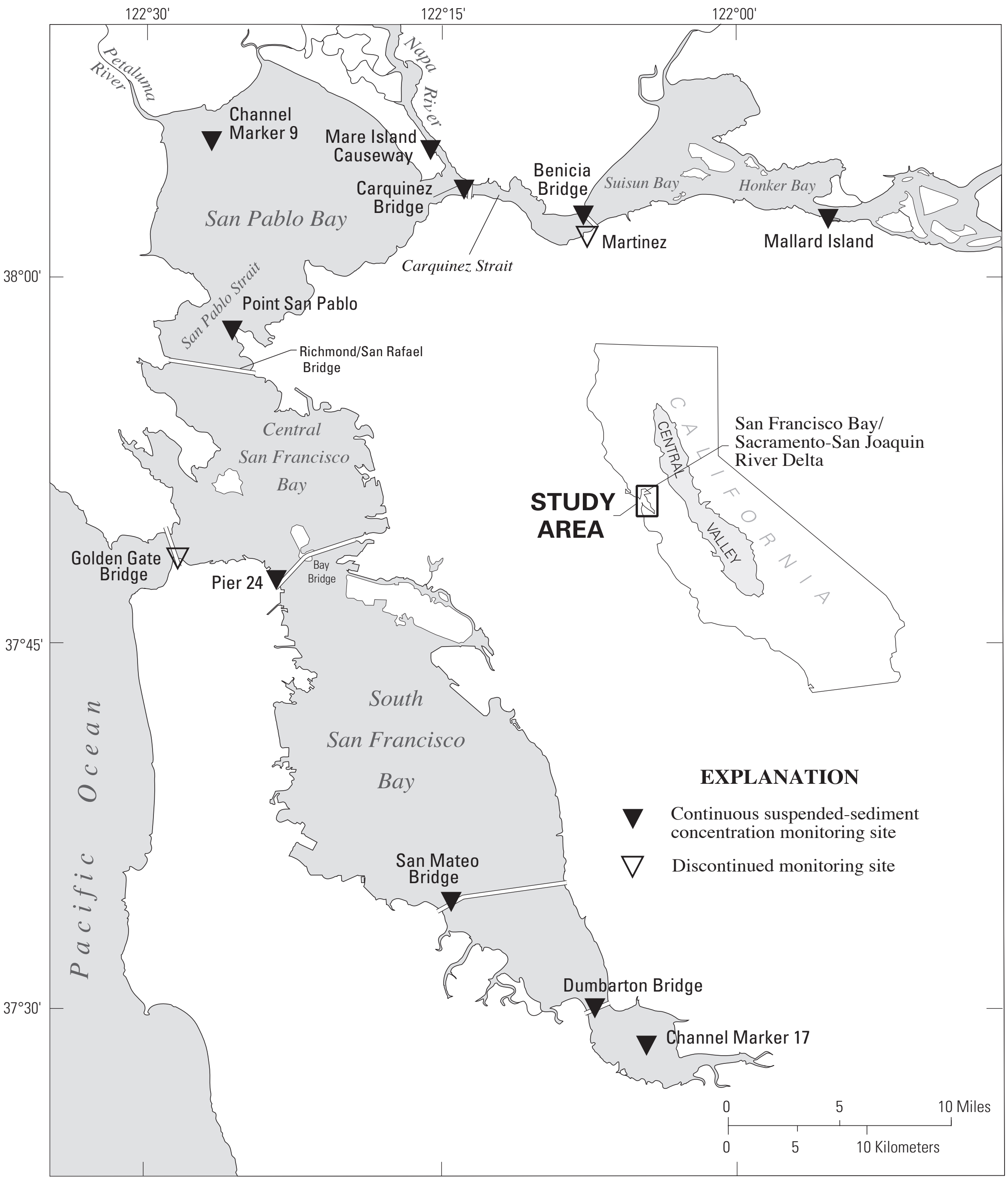

Figure 1. San Francisco Bay study area, California.

METHODS

Instrument Description and Operation

Three types of optical backscatterance sensors were used to monitor concentrations of suspended sediment during water year 2000. The first type of sensor is manufactured by D & A Instrument Company and is a cylinder approximately 7 inches (in.) long and 1 in. in diameter with an optical window at one end, a cable connection at the other end, and an encased circuit board (Downing and others, 1981; Downing, 1983). A high-intensity infrared emitting diode produces a beam through the optical window that is scattered, or reflected, by particles that are about 0.2–12 in. in front of the window. A detector (four photodiodes) receives backscatter from a field of 140–165° (D & A Instrument Company, 1991); backscatter is converted to a voltage output and recorded on a separate data logger. The second type of sensor, manufactured by BTG, is self-cleaning and similar in size and function to the other optical sensors used in the study, but each self-cleaning probe has a separate electronic unit that sets the resolution and maximum reading, expressed in Nephelometric Turbidity Units (NTU). The voltage output from the electronic unit is recorded on a separate data logger. The third type of sensor, manufactured by Hydrolab, is part of a multiprobe that also measures specific conductance, temperature, and depth. The Hydrolab optical backscatterance sensor measures the intensity of light scattered at 90° from two light-emitting diodes and is expressed in NTU. The multiprobe (sonde) is self contained with a power source and data logger.

The optical backscatterance data collected by the sonde turbidity sensor were poor in the range of 50 to 70 NTU; this problem was traced to an error in a linearization table in the sensor software. The table converts raw sensor readings to NTU, and an erroneous value of near zero was mistakenly entered for the value corresponding to 60 NTU, while all other entries, including adjacent entries at 50 and 70 NTU, were correct. The resulting measured values are not correctable between 0 and 50 NTU, as three actual NTU values are possible—a low value, intermediate value, and high value (as shown with a measured value of 20 NTU, fig. 2). While these data are not considered valid, they are included in time-series plots to illustrate the range of values possible at the site. Data measured between 50 and 70 NTU are correctable because the actual value can be calculated using the following equation:

$$\text{Actual value} = (\text{Measured value} + 420) \div 7$$

For a measured value of 60 NTU, the corresponding actual value is 68.6 NTU (fig. 2). These data were corrected and included as valid data. Statistical quantities were computed assuming a SSC value equivalent to one-half of 50 NTU (25 NTU) for all data points between 0 and 50 NTU.

The voltage output for all three types of sensors is proportional to the concentration of suspended sediment in the water column at the depth of the sensor. Suspended-sediment concentrations calculated from the output of side-by-side sensors with and without the self-cleaning function (BTG and D&A Instrument Company), are virtually identical (Buchanan and Schoellhamer, 1998, fig. 4). Calibration of the sensor voltage output to concentrations of suspended sediment will vary according to the size and optical properties of the suspended sediment; therefore, the sensors must be calibrated using suspended material from the field (Levesque and Schoellhamer, 1995).

Optical sensors were positioned in the water column using polyvinyl chloride (PVC) pipe carriages coated with an antifoulant paint to impede biological growth. Carriages were designed to align with the direction of flow and to ride along a stainless steel or Kevlar-reinforced nylon suspension line attached to an anchor weight, which allowed sensors to be easily raised and lowered for servicing (fig. 3). The plane of the optical window maintained a position parallel to the direction of flow as the carriage and sensor aligned itself with the changing direction of flow.

Data acquisition were controlled by an electronic data logger. The logger was programmed to power the optical sensor every 15 minutes, collect data each second for 1 minute, then average and store the output voltage for that 1-minute period. Power was supplied by 12-volt (V) direct current, 12-ampere hour (Ah), gel-cell batteries, except for the sonde, which used eight size-C alkaline batteries.

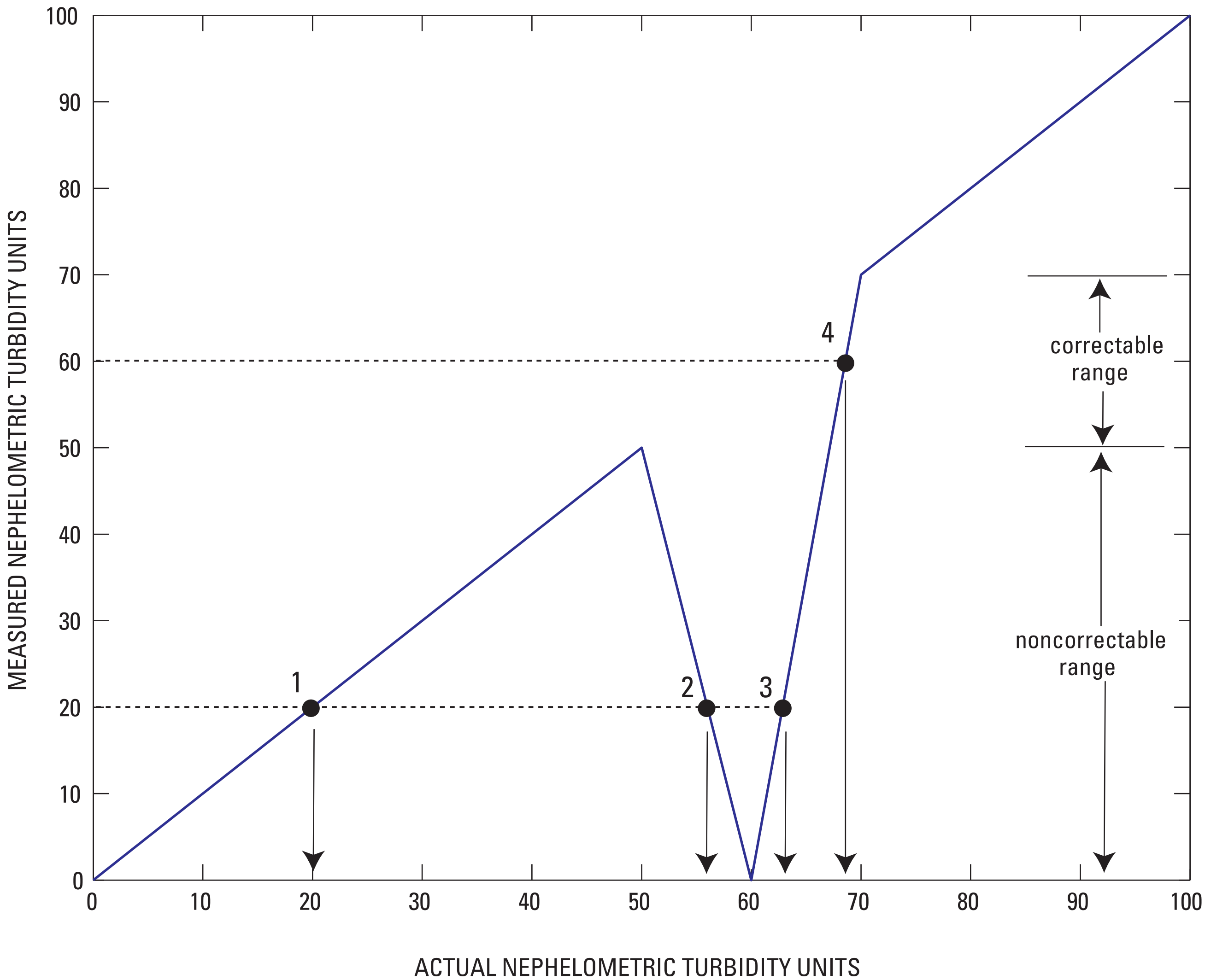

Figure 2. Sonde turbidity sensor linearization error. For measured values between 0 nd 50 NTU (noncorrectable range) three actual values are possible: low (1), intermediate (2), and high (3). For measured values between 50 and 70 NTU (correctable range), data can be corrected to yield the actual value (4).

Self-cleaning optical sensors with wipers were deployed at four sites during water year 1994 to reduce biological growth, which interferes with the collection of accurate optical backscatterance data. Because the self-cleaning sensor requires 95 to 130-V alternating current (AC), installation was limited to sites with AC power. The self-cleaning probes and electronic units were installed at two sites in Suisun Bay and at two sites in South Bay. Fouling in Suisun Bay was minor compared with that in South and Central Bays, and the self-cleaning probes were effective in keeping optical ports clean. However, fouling at the two sites in South Bay during summer was so extreme that the self-cleaning probes often were rendered ineffective by biological growth on the carriage and wiper mechanism. During water year 1995, all self-cleaning probes deployed in South Bay failed due to salt crystals forming on an O-ring, which resulted in water leakage. To address the leakage problem, the design was modified by the manufacturer. In water year 1996, an updated version of the self-cleaning probe was deployed at the Dumbarton Bridge site in South Bay, but it failed within the first month of operation. Thereafter, the self-cleaning probes were used only at the less saline Mallard Island site in Suisun Bay.

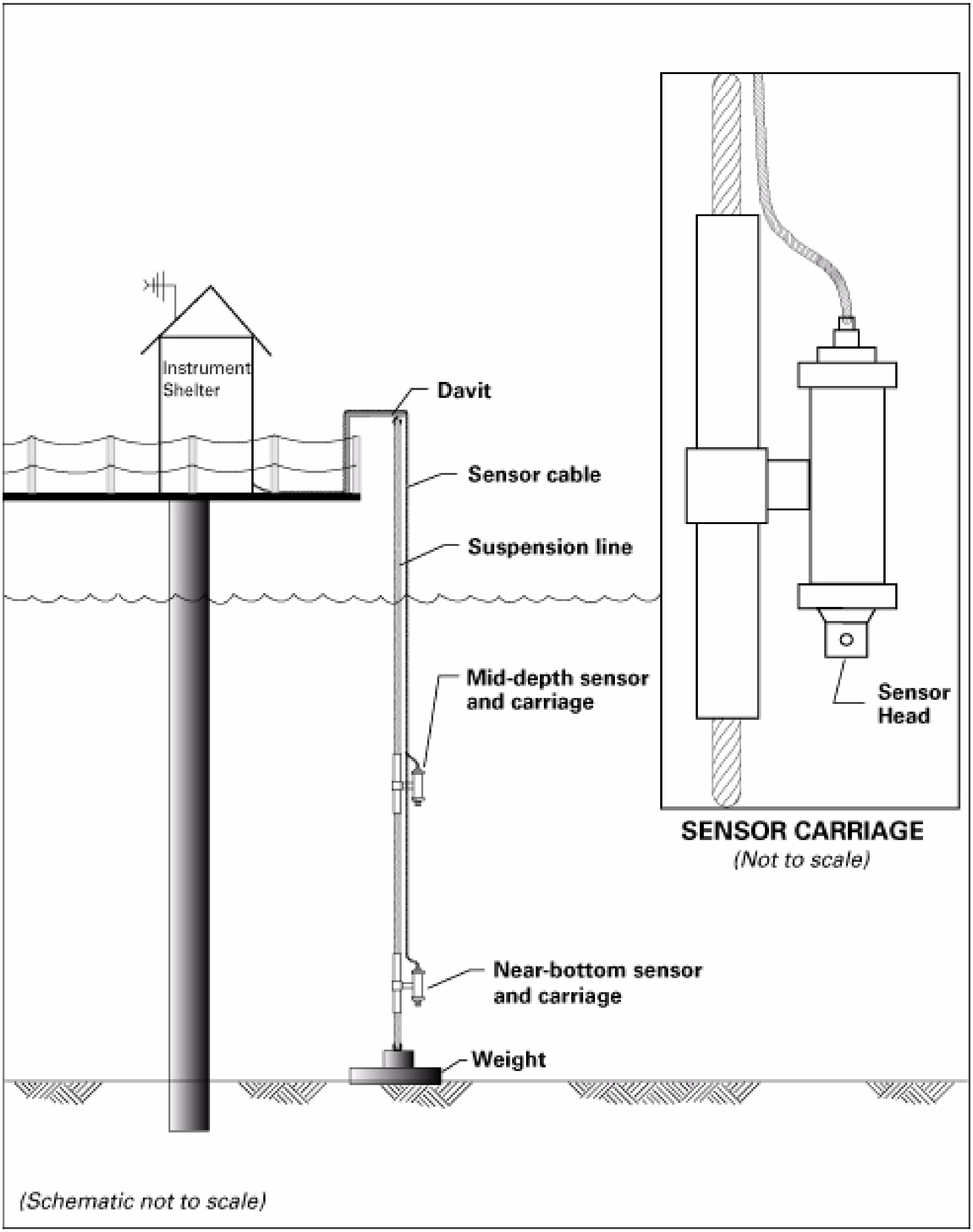

Figure 3. Typical monitoring installation, San Francisco Bay study.

Fouling generally was greatest on the sensor closest to the water surface. However, at shallower sites where the upper sensor was set 10 ft above the lower sensor, the degree of fouling was similar on both sensors. Optical sensors required frequent cleaning but, due to the difficulty in servicing some of the monitoring stations, they were cleaned every 1-5 (usually 3) weeks. Fouling would begin to affect sensor output from 2 days to several weeks after cleaning, depending on the level of biological activity in the Bay. Generally, biological fouling was greatest during spring and summer.

On-site checks of sensor accuracy were performed using turbidity solutions prepared from a 4,000-NTU formazin standard. Formazin is an aqueous suspension of an insoluble polymer and is specified as the primary turbidity standard by the U.S. Environmental Protection Agency (Greenberg and others, 1992). The turbidity solutions are prepared by diluting a 4,000-NTU stock standard with high-purity water in a clean, sealable bucket. Prepared solutions ranged from 50 to 200 NTU. At the field site, the cleaned sensors are immersed in the solution and the voltage output is recorded on the station log. Monitoring a period of sensor performance in a known standard helps to identify output drift or sensor malfunction.

Suisun Bay Installations

Suspended-sediment monitoring equipment was installed at Mallard Island during water year 1994, and Benicia Bridge during water year 1996 (fig. 1; table 1). Monitoring was shut down in August 1998 at Carquinez Strait at Benicia Bridge during seismic retrofitting and will be reestablished at a future date. The monitoring site at the Martinez Marina fishing pier was discontinued in water year 1996 because data from the Benicia Bridge were considered more representative of suspended-sediment concentration in the Carquinez Strait area of Suisun Bay (Buchanan and Schoellhamer, 1998).

Table 1. Statistical summary of suspended-sediment concentration data, Suisun Bay, San Pablo Bay, and Central and South San Francisco Bays, California, water year 2000

[All measurements are in milligrams per liter. Lower quartile is 25th percentile; upper quartile is 75th percentile]

Site	Station No.	Latitude	Longitude	Depth	Mean	Median	Lower quartile	Upper quartile
Mallard Island	11185185	38°02’34”	121°55’09”	Near-surface	37	34	27	45
				Near-bottom	48	44	32	57
Carquinez Bridge	11455820	38°03’41”	122°13’23”	Mid-depth	56	37	37	37
				Near-bottom	85	34	34	112
Mare Island Causeway	11458370	38°06’40”	122°16’25”	Mid-depth	76	57	39	94
				Near-bottom	180	136	85	224
Channel Marker 9	380519122262901	38°05’19”	122°26’29”	Near-bottom	203	110	25	280
Point San Pablo	11181360	37°57’53”	122°25’42”	Mid-depth	43	40	24	54
				Near-bottom	59	47	33	72
Pier 24	11162700	37°47’27”	122°23’05”	Mid-depth	23	21	19	24
				Near-bottom	32	28	23	36
San Mateo Bridge	11162765	37°35’04”	122°14’59”	Mid-depth	42	29	17	45
				Near-bottom	42	31	23	50
Dumbarton Bridge	373015122071000	37°30’15”	122°07’10”	Mid-depth	69	58	44	82
				Near-bottom	112	97	67	139
Channel Marker 17	372844122043800	37°28’44”	122°04’38”	Mid-depth	110	85	53	138
				Near-bottom	143	98	58	172

Mallard Island

Self-cleaning optical sensors were installed at the DWR Mallard Island Compliance Monitoring Station on February 8, 1994. This site is about 5 miles (mi) downstream from the confluence of the Sacramento and San Joaquin Rivers and is at the north shore of Mallard Island near the eastern boundary of Honker Bay, a subembayment of Suisun Bay (fig. 1; table 1). The station was constructed in the early 1980's by DWR on Pacific Gas and Electric Company property, and water-quality data were first recorded at the station in January 1984. A 1/4-mi wooden walkway crosses the sometimes submerged reedbeds of Mallard Island and connects the concrete block instrument shelter to the levee road.

Sensors were positioned at near-bottom (5 ft above the bottom) and near-surface (3.3 ft below the surface) depths to coincide with DWR near-bottom depth electrical conductance and temperature sensors and the near-surface pump intake. The pump intake was attached to a float that is housed inside a 12-in. PVC pipe, and the intake drew water from about 3 ft below the surface. Mean lower low water depth at this site was about 25 ft. DWR near-surface parameters were measured by sensors submerged in flow-through chambers inside the instrument shelter. This configuration saved the cost of installing duplicate sets of sensors and enabled the USGS to use DWR instruments for data, such as stage, pH, chlorophyll concentration, and meteorological parameters.

Data storage was controlled by a data logger connected to a cellular phone and modem. AC power operated both optical sensors and charged a 12-V, 12-Ah battery that powered the data logger and modem. The data logger and peripheral equipment were housed in the instrument shelter. The sensors were suspended from a galvanized support stand that was attached to a metal railing on the station's northwest concrete deck. The support stand had two stainless-steel lines attached to separate concrete weights; one line for the near-bottom sensor and one line for the near-surface sensor. The near-bottom sensor was attached to a PVC carriage suspended from the stainless-steel line by a nylon rope. The near-surface sensor was attached to a PVC carriage that was built onto a float. This float assembly moved up and down the suspension line during tidal cycles, which maintained the near-surface sensor at the same depth as the DWR pump intake. A pressure transducer was positioned on the float assembly at the same level as the sensor and provided data to verify the depth of the near-surface sensor. To prevent sensor cables from being snagged by debris, a counterweight was installed to keep slack cables out of the water.

San Pablo Bay Installations

Carquinez Bridge

Suspended-sediment monitoring equipment was installed April 21, 1998, at the Carquinez Bridge on the north side of the center pier structure (fig. 1; table 1). Sondes with optical, specific conductance, temperature, and depth sensors were deployed at near-bottom and mid-depths (5 ft and 48 ft, respectively, from the bottom). Mean lower low water depth at this site was about 88 ft. The sensors were suspended between the concrete pier superstructure and the fender boards, which were approximately 1 ft apart. PVC carriages attached to 1/4-in. stainless-steel line were anchored to a 250-pound (lb.) weight and used to suspend the sensors at the desired depth. Data acquisition was controlled by an internal data logger powered by eight size-C alkaline batteries that were replaced during site visits. No instrument shelter was needed at this site.

Mare Island Causeway

The USGS established a monitoring site on the Napa River at Mare Island Causeway near Vallejo in water year 1998 (fig. 1; table 1) in cooperation with the California Coastal Conservancy. The USGS assumed full operation of this site in water year 1999. Optical sensors were installed on October 1, 1998, and were positioned at near-bottom and mid-depth (5 ft and 15 ft, respectively, from the bottom). Mean lower low water depth at this site was about 30 ft. Specific conductance and temperature data were collected at near-bottom and near-surface points in the water column (near-bottom and near-surface depths were sampled to define the vertical stratification). PVC carriages attached to 1/4-in. stainless-steel line anchored to a 125-lb. weight suspend the sensors at the desired depth. Data acquisition was controlled by a data logger. AC power charged a 12-V, 12-Ah battery that powered the data logger and sensors. The data logger and peripheral equipment were housed in a 3×2×1-ft plastic weather-proof shelter mounted on a catwalk underneath the causeway.

Channel Marker 9

Suspended-sediment monitoring equipment was installed November 12, 1998, at USCG Channel Marker 9. This site was located in the navigation channel leading to the Petaluma River in the northwest corner of San Pablo Bay (fig. 1; table 1). A sonde with optical, specific conductance, temperature, and depth sensors was deployed at near-bottom depth (2 ft above the bottom). Mean lower low water depth at this site was about 6 ft. The sensor was suspended from the channel marker platform using a PVC carriage attached to 1/4-in. stainless-steel line anchored to a 125-lb. weight. Data acquisition was controlled by an internal data logger powered by eight size-C alkaline batteries that were replaced during site visits. No instrument shelter was needed at this site.

Central San Francisco Bay Installations

Point San Pablo

The USGS maintains a monitoring site at San Pablo Strait on the northern end of the Richmond Terminal No. 4 pier on the west side of Point San Pablo (fig. 1; table 1). The USGS assumed operation of this site from DWR in October 1989. Data collected prior to October 1, 1989, can be obtained from DWR.

Optical sensors were installed at Point San Pablo on December 1, 1992, and were positioned at near-bottom and middle depths (3 ft and 13 ft, respectively, from the bottom). Mean lower low water depth at this site was about 26 ft. Specific conductance and temperature data (cooperatively funded by DWR and the USGS) were collected at near-bottom and near-surface depths in the water column (near-bottom and near-surface depths were sampled to define vertical stratification). Data acquisition was controlled by a data logger connected to a phone line and modem. PVC carriages attached to 1/4-in. stainless-steel line anchored to a 125-lb. weight suspend the sensors at the desired depth. Water level was recorded using a float-driven incremental encoder wired into the data logger; water levels were read during site visits using a wire-weight gage. AC power charged a 12-V, 60-Ah battery that powered the data logger and sensors. The data logger and peripheral equipment were housed in a 5×8×8-ft wooden shelter.

Pier 24

The monitoring station at Pier 24 is on the west side of the San Francisco-Oakland Bay Bridge (fig. 1; table 1). The USGS assumed operation of this station from DWR in October 1989. Data collected prior to October 1, 1989, can be obtained from DWR.

Optical sensors were installed at the Pier 24 site on May 25, 1993, and were positioned at near-bottom and middle depths (3 ft and 23 ft, respectively, from the bottom). Mean lower low water depth at this site was about 41 ft. As at the Point San Pablo station, specific conductance and temperature data (cooperatively funded by DWR and the USGS) were collected at near-bottom and near-surface depths in the water column. PVC carriages attached to 1/4-in. stainless-steel line anchored to a 125-lb. weight suspend the sensors at the desired depth. Data acquisition was controlled by a data logger connected to a cellular phone and modem. AC power charged two 12-V, 12-Ah batteries that powered the instrumentation. The data logger and peripheral equipment were housed in a corrugated steel shelter.

South San Francisco Bay Installations

San Mateo Bridge

The monitoring site on the San Mateo Bridge is at Pier 20 on the east side of the ship channel (fig. 1; table 1). This station was operated by DWR, but the USGS assumed operations in October 1989. Data collected prior to October 1, 1989, can be obtained from DWR.

The optical sensors were installed on December 23, 1991, and were positioned at near-bottom and middle depths (8 ft and 29 ft, respectively, above the bottom). Mean lower low water depth at this site was about 48 ft. The sensors were deployed between the pier and a protective fender structure composed of multiple piles: flow past the sensors was affected significantly by the pilings and the concrete superstructure. PVC carriages attached to 1/4-in.

stainless-steel line anchored to a 200-lb. weight suspend the sensors at the desired depth. Data acquisition was controlled by a data logger. In addition to suspended-sediment concentrations, specific conductance and temperature (cooperatively funded by DWR and the USGS) were monitored at near-bottom and near-surface depths. AC power charged a 12-V, 60-Ah battery that powered the data logger and sensors. The data logger and peripheral equipment were housed in an 8×6×8-ft wooden shelter on the pier.

Dumbarton Bridge

Suspended-sediment concentration monitoring equipment was installed on October 21, 1992, at Pier 23 of the Dumbarton Bridge on the west side of the ship channel (fig. 1; table 1). Optical sensors were deployed at near-bottom and middle depth (4 ft and 23 ft, respectively, from the bottom). Mean lower low water depth was about 45 ft. The sensors were suspended between the concrete pier superstructure and its surrounding protective fender boards, a space approximately 3 ft wide. Data acquisition was controlled by a data logger. PVC carriages attached to 1/4-in. stainless-steel line anchored to a 125-lb. weight suspend the sensors at the desired depth. AC power charged a 12-V, 12-Ah battery that powered the instrumentation. The data logger and peripheral equipment were housed in a 3×2×1-ft plastic weather-proof shelter mounted on the pier.

Channel Marker 17

The southernmost monitoring site in South Bay is at the USCG Channel Marker 17 (fig. 1; table 1). Instrumentation was installed on February 26, 1992, and the optical sensors were positioned at near-bottom and middle depths (3 ft and 13 ft, respectively, from the bottom). Mean lower low water depth at this site was about 25 ft. Sensor cables were protected by a 10-ft PVC pipe suspended from the channel marker platform. Data acquisition was controlled by a data logger. PVC carriages attached to 1/4-in. Kevlar-reinforced nylon line anchored to a 100-lb. weight suspend the sensors at the desired depth. The data logger and 12-V, 12-Ah batteries were housed in a 2×2×1-ft plastic weather-proof shelter mounted on the channel marker platform.

Water-Sample Collection

Water samples, used to calibrate the voltage output of the optical sensors to suspended-sediment concentrations, were collected using a horizontally positioned Van Dorn sampler before and after the sensors were cleaned. The Van Dorn sampler is a plastic tube with rubber stoppers at each end that snap shut when triggered by a small weight dropped down the suspension cable. The Van Dorn sampler was lowered to the depth of the sensor by a reel and crane assembly and triggered while the sensor was collecting data. Water samples were marked for identification and placed in an ice chest to limit biological growth. The suspended-sediment concentration of water samples collected with a Van Dorn sampler and a P-72 point sampler, used until water year 1994, were compared and found to be virtually identical (Buchanan and others, 1996, fig. 2).

Water samples were sent to the USGS Sediment Laboratory in Salinas, California, for analysis of suspended-sediment concentration. Suspended sediment includes all particles in the sample; the suspended sediment (material that settles to the bottom of the sample bottle) and buoyant particles that do not settle. Suspended-sediment concentrations were referred to as suspended-solids concentration in previous reports (Buchanan and Schoellhamer, 1995, 1996, 1998, 1999; Buchanan and others, 1996; Buchanan and Ruhl, 2000, 2001). The analytical method used to quantify concentrations of suspended solid-phase material defines the nomenclature used to describe sediment data (Gray and others, 2000). Water samples used in this and previous reports were analyzed for suspended-sediment concentration (total water-sediment mass and all sediment were measured). Each sample was filtered through a 0.45-micrometer membrane filter, the filter was rinsed to remove salts, and the insoluble material was dried at 103°C and weighed (Fishman and Friedman, 1989).

Data Processing

Data loggers stored the voltage outputs from the optical sensors at 15-minute intervals (96 data points per day) (table 2). Recorded data were downloaded from the data logger onto a storage module during site visits. Raw data from the storage modules were loaded into the USGS automated data-processing system (ADAPS).

The time-series data were retrieved from ADAPS and edited using MATLAB software to remove invalid data. Invalid data included rapidly increasing voltage outputs and unusually high voltage outputs of short duration (spikes). As biological growth accumulated on the optical sensors, the voltage output of the sensors increased (except for the sondes, which decreased). An example time series of raw and edited optical backscatterance data from water year 1994 is presented in figure 4. After sensors were cleaned, sensor output immediately decreased (fig. 4, April 19, June 8, and June 28). Efforts to correct the invalid data prior to cleaning proved unsuccessful because the true signal was sometimes highly variable. Thus, data collected during the period prior to sensor cleaning often were unusable and were removed from the record (fig. 4). Spikes in the data, which are anomalously high voltages, probably caused by debris temporarily wrapped around the sensor or by large marine organisms (fish, crabs) on or near the sensor, also were removed from the raw data record (fig. 4). Sometimes, incomplete cleaning of a sensor would cause a small, constant shift in sensor output that could be corrected using water-sample data.

Table 2. Percentage of 1 complete year of valid data (96 data points per day) collected by optical backscatterance sensors, Suisun Bay, San Pablo Bay, and Central and South San Francisco Bays, California, water year 2000

Site	Depth	Percent valid data
Mallard Island	Near-surface	87
	Near-bottom	64
Carquinez Bridge	Mid-depth	12
	Near-bottom	35
Mare Island Causeway	Mid-depth	78
	Near-bottom	74
Channel Marker 9	Near-bottom	43
Point San Pablo	Mid-depth	61
	Near-bottom	75
Pier 24	Mid-depth	51
	Near-bottom	59
San Mateo Bridge	Mid-depth	9
	Near-bottom	22
Dumbarton Bridge	Mid-depth	47
	Near-bottom	55
Channel Marker 17	Mid-depth	51
	Near-bottom	50

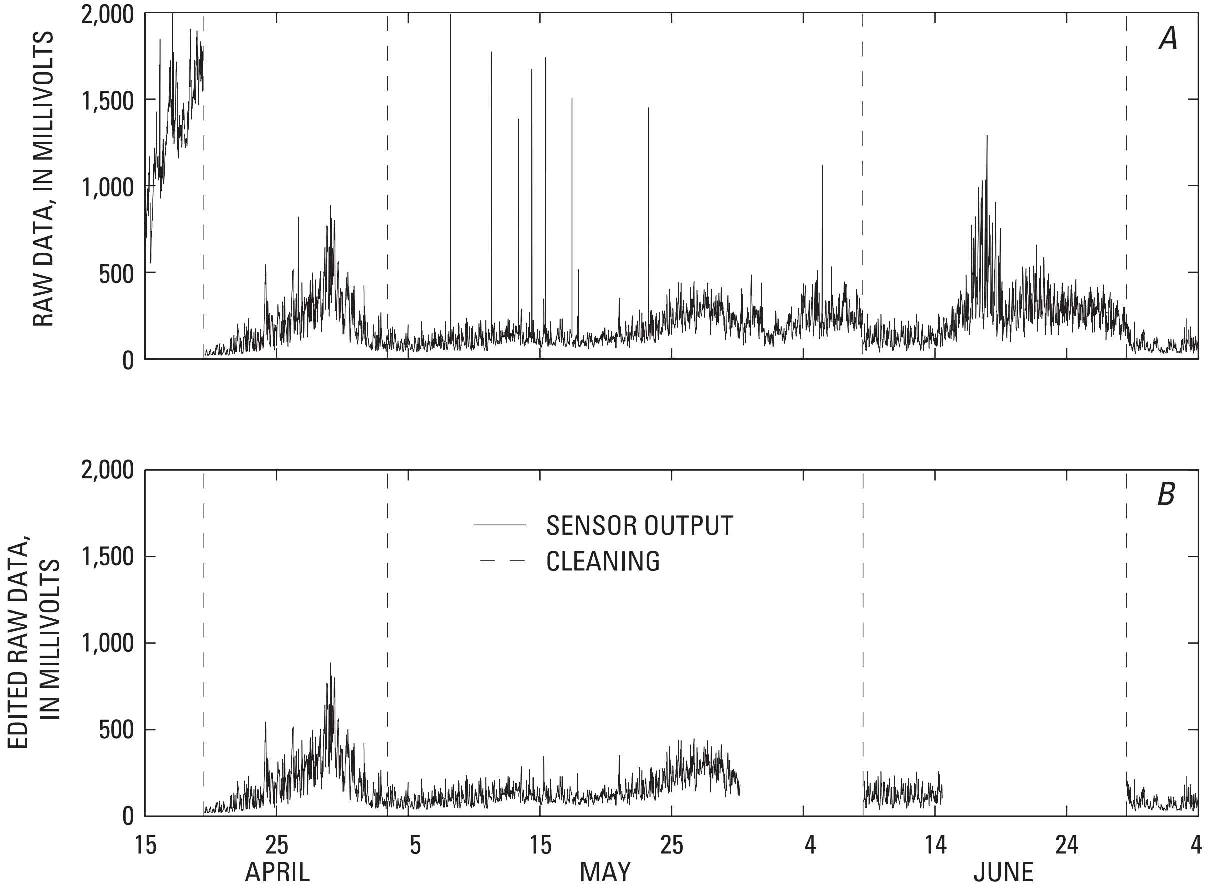

Figure 4. Example of raw (*A*) and edited (*B*) optical backscatterance data, mid-depth sensor, Point San Pablo, Central San Francisco Bay, California, water year 1994 (Buchanan and others, 1996).

SENSOR CALIBRATION AND SUSPENDED-SEDIMENT CONCENTRATION DATA

Output from the optical sensors was converted to suspended-sediment concentration using the robust, nonparametric, repeated median method (Siegel, 1982). The prediction interval and the 95-percent confidence interval were calculated and presented for each calibration equation.

The repeated median method calculates the slope in a two-part process. First, for each point (X,Y), the median of all possible "point i" to "point j" slopes was calculated

$$\beta_i = median\frac{(Y_j - Y_i)}{(X_j - X_i)} \qquad \text{for all } j \neq i .$$

The calibration slope was calculated as the median of β_i

$$\text{slope} = \hat{\beta}_1 = median(\beta_i) .$$

Finally, the calibration intercept was calculated as the median of all possible intercepts using the slope calculated above

$$\text{intercept} = \hat{\beta}_0 = median(Y_i - \hat{\beta}_1 X_i)\,.$$

The final linear calibration equation is

$$Y = \hat{\beta}_1 X + \hat{\beta}_0\,.$$

The nonparametric prediction interval (PI_{np}) (Helsel and Hirsch, 1992, p. 76) is a constant-width error band that contains 68.26 percent, or one standard deviation, of the calibration data set. The 68.26-percent value was selected because it has essentially the same error prediction limits as the root-mean-squared (RMS) error of prediction in ordinary least squared regression: the latter was used in previous data reports (Buchanan and Schoellhamer, 1995, 1996, 1998, 1999; Buchanan and others, 1996) to analyze random sets of normally distributed data. The prediction interval describes the likelihood that a new observation comes from the same distribution as the previously collected data set.

The PI_{np}, unlike the RMS error of prediction, frequently is not symmetrical about the regression line. For example, the PI_{np} may be reported as +10 milligrams per liter (mg/L) and -7 mg/L. This asymmetry about the regression line is a result of the nonnormal distribution of the data. The PI_{np} is calculated by computing and sorting, from least to greatest, the residuals for each point. Then, based on the sorted list of residuals

$$\text{nonparametric prediction interval} = PI_{np} = \hat{Y}_{\left(\frac{\alpha}{2}\right)(n+1)} \text{ to } \hat{Y}_{\left(1-\frac{\alpha}{2}\right)(n+1)}\,,$$

where

$\hat{Y}$ is the residual value,

n is the number of data points, and

α is the confidence level of 0.6826.

To calculate the confidence interval, all possible point-to-point slopes must be sorted in ascending order. Based on the confidence interval desired (95 percent for the purposes of this report), the ranks of the upper and lower bounds are calculated as follows:

$$Ru = \left(\frac{\frac{n(n-1)}{2} + 1.96\left(\sqrt{\frac{n(n-1)(2n+5)}{18}}\right)}{2} + 1\right), \text{ and}$$

$$Rl = \frac{\frac{n(n-1)}{2} - 1.96\left(\sqrt{\frac{n(n-1)(2n+5)}{18}}\right)}{2}$$

where

Ru is the rank of the upper bound slope,

Rl is the rank of the lower bound slope, and

n is the number of samples.

To establish the 95-percent confidence interval, the ranks calculated above are rounded to the nearest integer and the slope associated with each rank in the sorted list is identified. This is a large-sample approximation and was used for each of the confidence intervals presented in this report. However, when fewer than 10 samples were collected, a direct calculation was made (Helsel and Hirsch, 1992, p. 273-274).

A statistical summary of the calculated suspended-sediment concentrations is presented in table 1. The percentage of 1 complete year of valid data (96 data points per day) collected by optical backscatterance sensors at each site is presented in table 2.

This section of the report also includes the robust regression (calibration) plots for optical sensor output versus suspended-sediment concentration (in milligrams per liter). The repeated median regression plots include the number of water samples, the calculated linear correlation equation, the nonparametric prediction interval (shown on the plots as a grey band), and the 95-percent confidence interval (shown on the plots as a dash-dot line). Finally, the time-series plots of suspended-sediment concentration data are shown for each site.

Suisun Bay

Mallard Island

The calibration of the near-surface, self-cleaning probe (fig. 5*A*) was developed from 25 water samples collected from June 29, 1999, (water samples from previous and succeeding water years are used to help define the calibration curve) through water year 2000. The calibration of the near-bottom self-cleaning probe (fig. 5*B)* was developed from 136 water samples collected from April 20, 1995, through water year 2000; flood samples collected from January through February 1997 and February through March 1998 were excluded (flood conditions, which can change sensor calibration, did not occur in water year 2000). Suspended-sediment concentration data collected during water year 2000 are presented in figure 6.

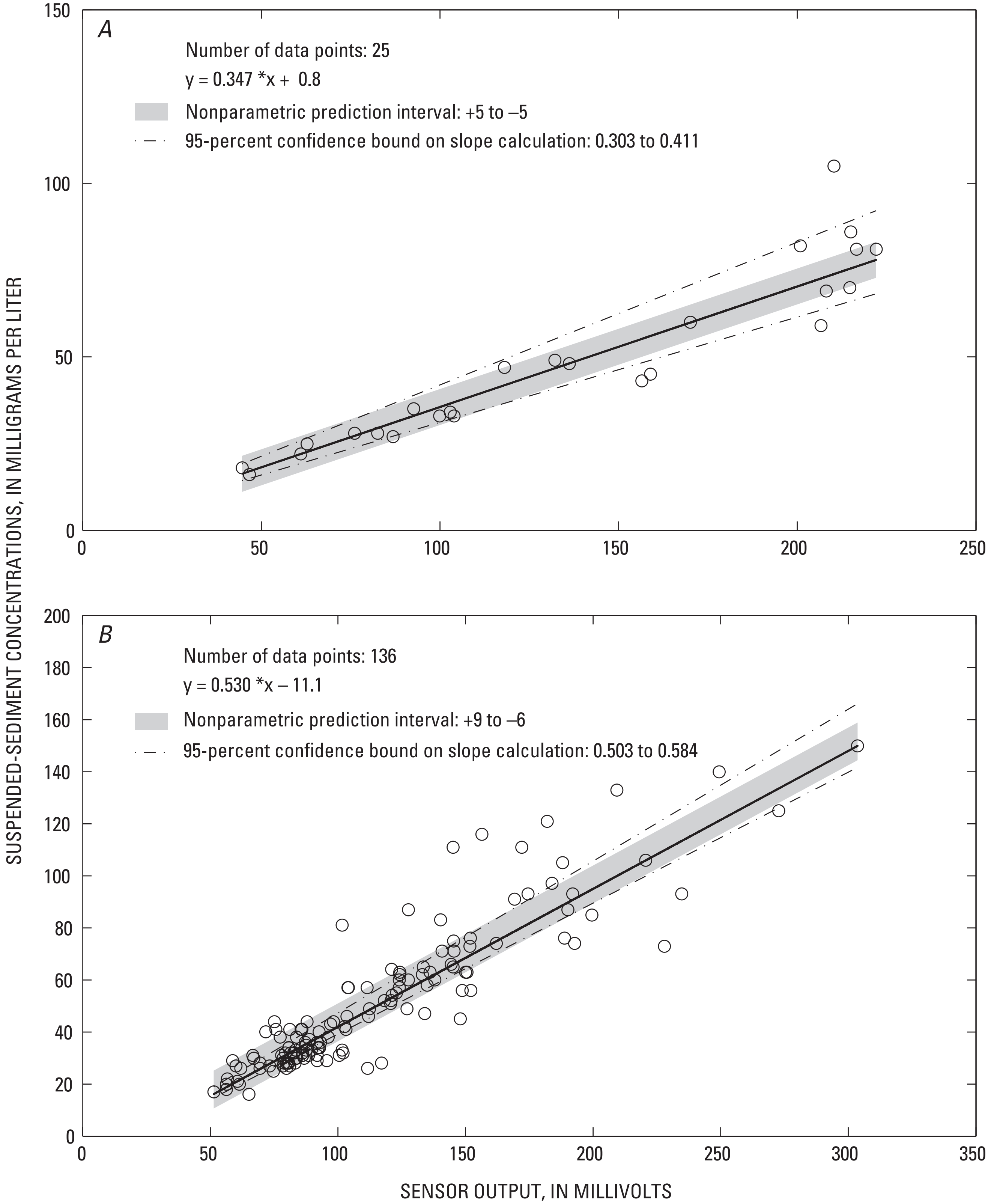

Figure 5. Calibration of near-surface (*A*) and near-bottom (*B*) optical backscatterance sensors at Mallard Island, Suisun Bay, California, water year 2000.

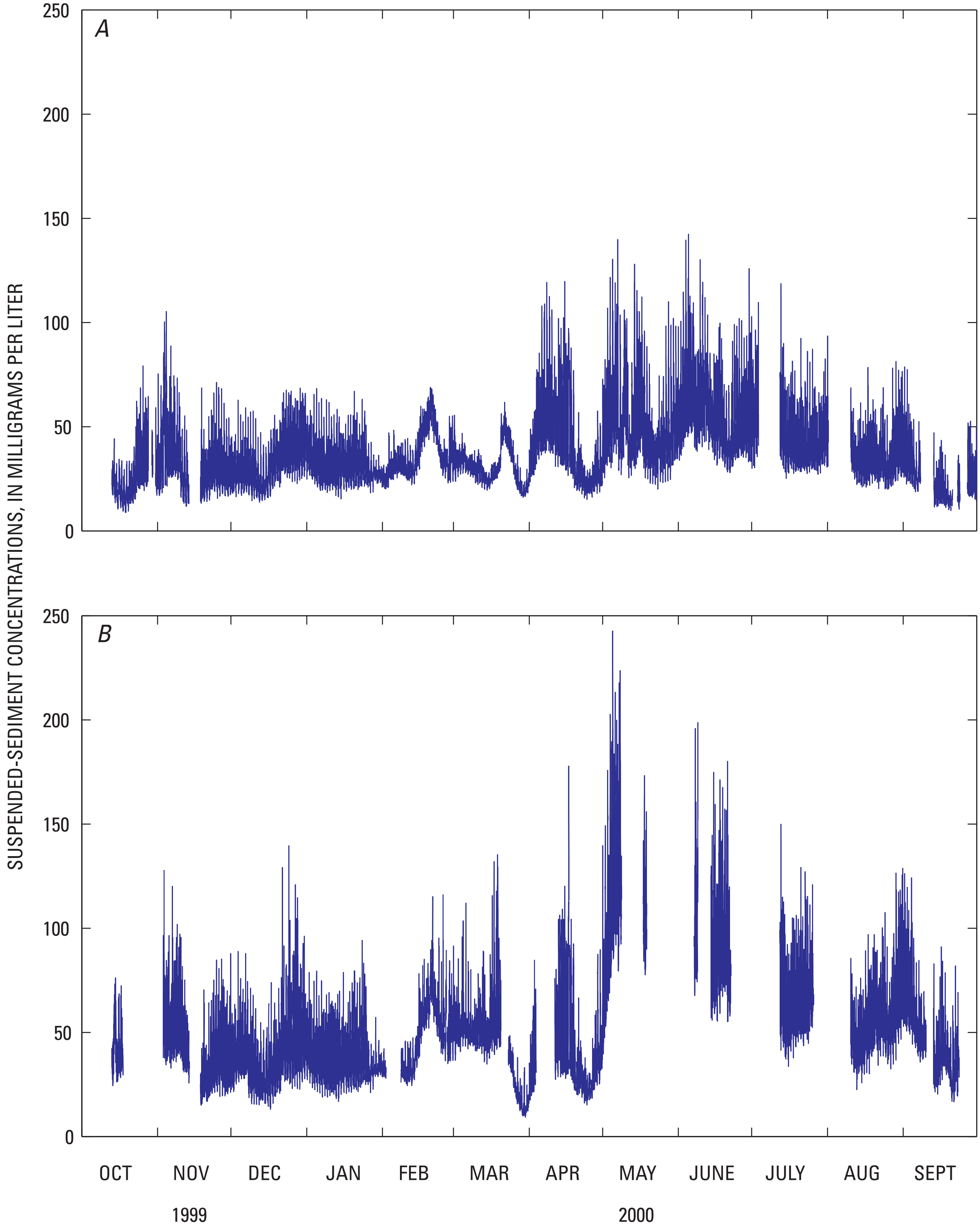

Figure 6. Time series of near-surface (*A*) and near-bottom (*B*) suspended-sediment concentrations calculated from sensor readings at Mallard Island, Suisun Bay, California, water year 2000.

San Pablo Bay

Carquinez Bridge

The suspension line for the sensors was found broken on October 29, 1999, and was replaced on November 4, 1999. The male pins on the mid-depth sonde's communication port were broken on October 29, and the sonde was out of service until December 21, 1999. The near-bottom sonde was redeployed on November 9, 1999. The suspension cable broke again during a site visit on August 22, 2000, and was replaced on August 28, when both sondes were redeployed. The calibration of the mid-depth sonde (fig. 7*A*) was developed from 13 water samples collected from June 10, 1999, through water year 2000. Mid-depth suspended-sediment concentration data between 13.1 and 74.2 mg/L are noncorrectable due to the error in the linearization table discussed earlier (fig. 2). The calibration of the near-bottom sonde (fig. 7*B*) was developed from 16 water samples collected from September 7, 1999, through water year 2000. Near-bottom suspended-sediment concentration data between 23.0 and 67.2 mg/L also are noncorrectable due to the error in the linearization table (fig. 2). Suspended-sediment concentration data collected during water year 2000 are presented in figure 8.

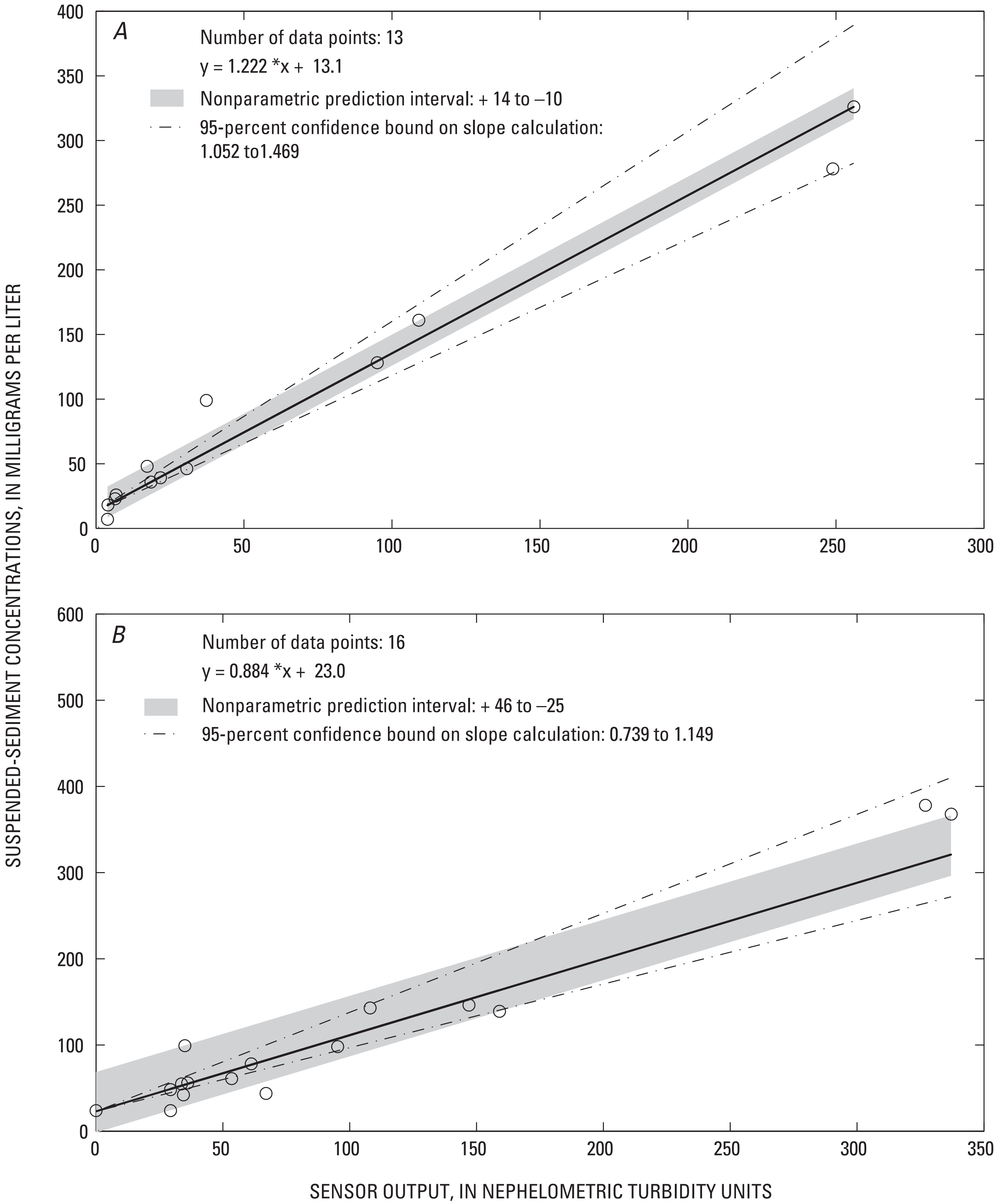

Figure 7. Calibration of mid-depth (*A*) and near-bottom (*B*) optical backscatterance sensors at Carquinez Bridge, San Pablo Bay, California, water year 2000.

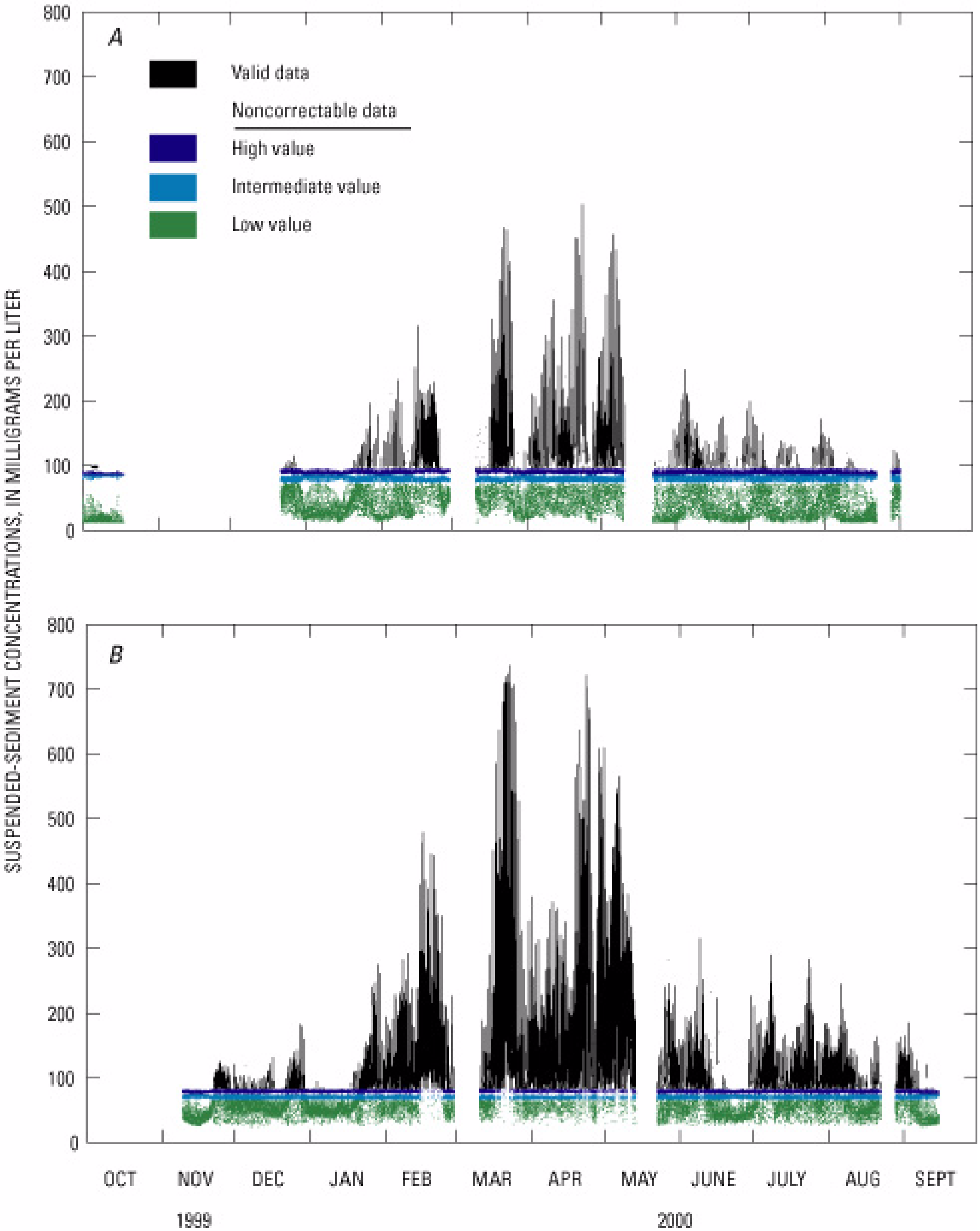

Figure 8. Time series of mid-depth (*A*) and near-bottom (*B*) suspended-sediment concentrations calculated from sensor readings at Carquinez Bridge, San Pablo Bay, California, water year 2000.

Mare Island Causeway

The calibration of the mid-depth sensor was developed from 57 water samples collected from October 6, 1998, through water year 2000 (fig. 9*A*). The calibration of the near-bottom sensor was developed from 51 water samples collected from October 6, 1998, through water year 2000 (fig. 9*B*). Suspended-sediment concentration data collected during water year 2000 are presented in figure 10.

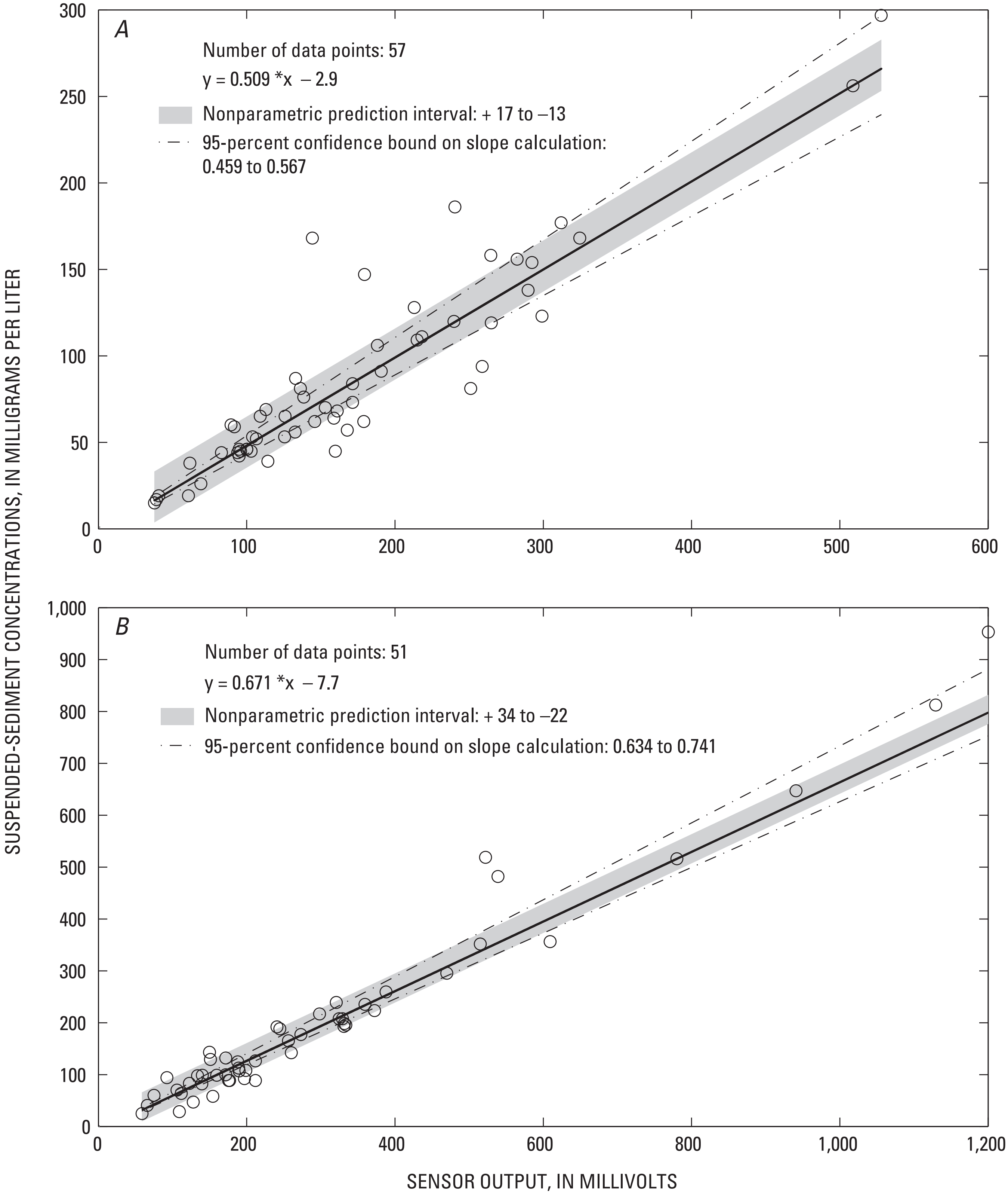

Figure 9. Calibration of mid-depth (*A*) and near-bottom (*B*) optical backscatterance sensors at Mare Island Causeway, San Pablo Bay, California, water year 2000.

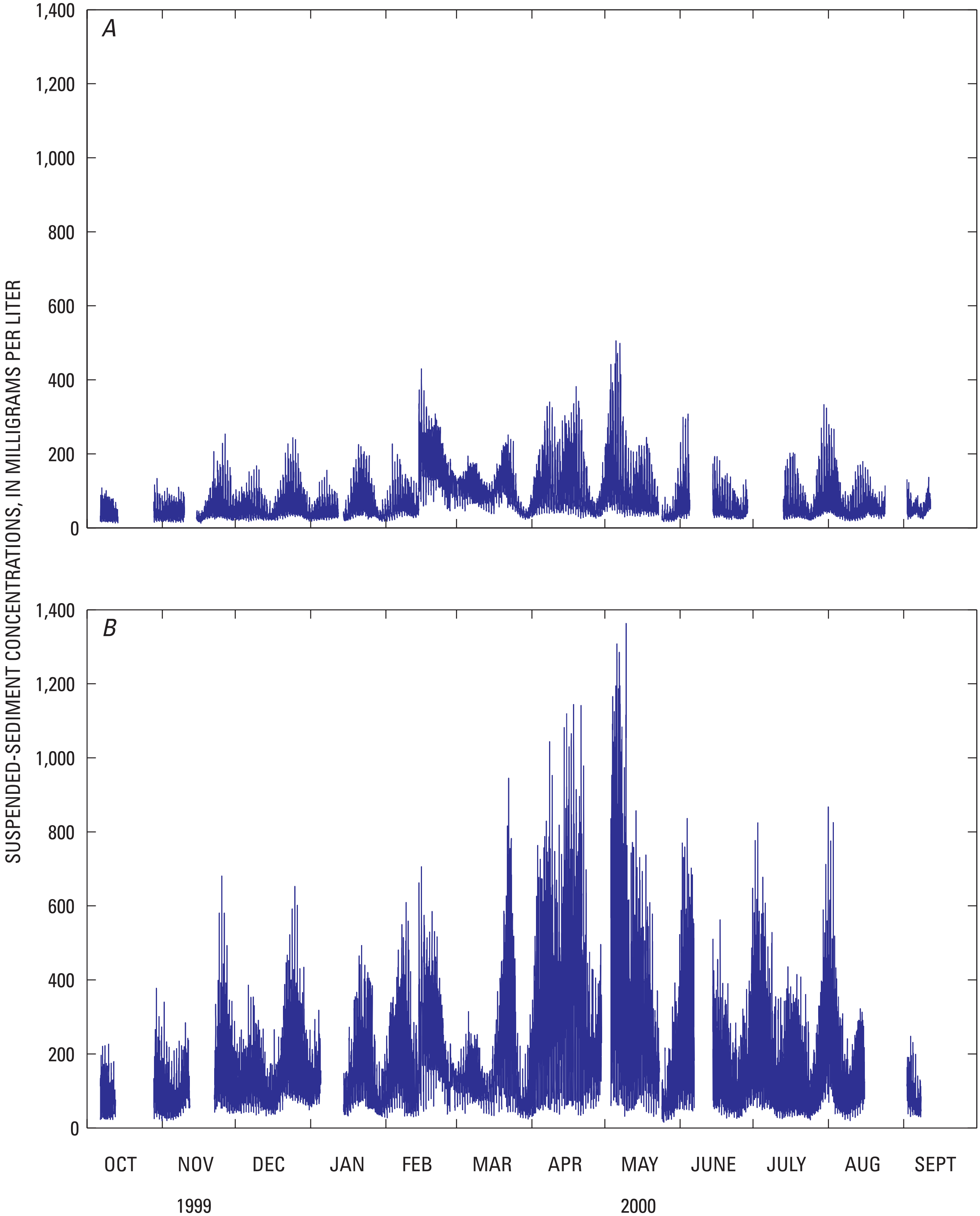

Figure 10. Time series of mid-depth (*A*) and near-bottom (*B*) suspended-sediment concentrations calculated from sensor readings at Mare Island Causeway, San Pablo Bay, California, water year 2000.

Channel Marker 9

Two sondes were deployed at Channel Marker 9 in water year 2000. The calibration of the sensor in place from October 1, 1999, through February 15, 2000, was developed from six samples collected from September 7, 1999, to February 15, 2000, and is considered poor (fig. 11*A*). Suspended-sediment data collected from October 1, 1999, to February 15, 2000, is noncorrectable between 13.0 and 187 mg/L due to the error in the linearization table (fig. 2). The sonde was replaced on February 15, 2000, because of problems with the electronic motherboard, which affected the turbidity and conductivity sensors. The originally deployed sonde was redeployed on April 18, replaced again on July 18 due to problems with the data logger and conductivity sensor, and redeployed September 26, 2000. A single calibration was used for both optical sensors for February 15 through September 30, 2000; the calibration was developed from 41 water samples (23 water samples collected from an auto-sampler operated on September 26-27, 2000) collected from November 12, 1998, to September 7, 1999, and February 15 through September 30, 2000 (fig. 11*B*). Using a single calibration for both sensors was possible because the sensors were factory calibrated using the same NTU standard and were verified using NTU standards of varying concentrations on-site during the period of deployment. The optical sensor on the sonde can measure a maximum of 1,000 NTU, which was sometimes exceeded at maximum ebb during a strong spring tide from February through September 2000. Suspended-sediment concentration data collected from February 15 to September 30, 2000, is noncorrectable between 26.4 and 85.6 mg/L due to the error in the linearization table (fig. 2). Suspended-sediment concentration data collected during water year 2000 are presented in figure 12.

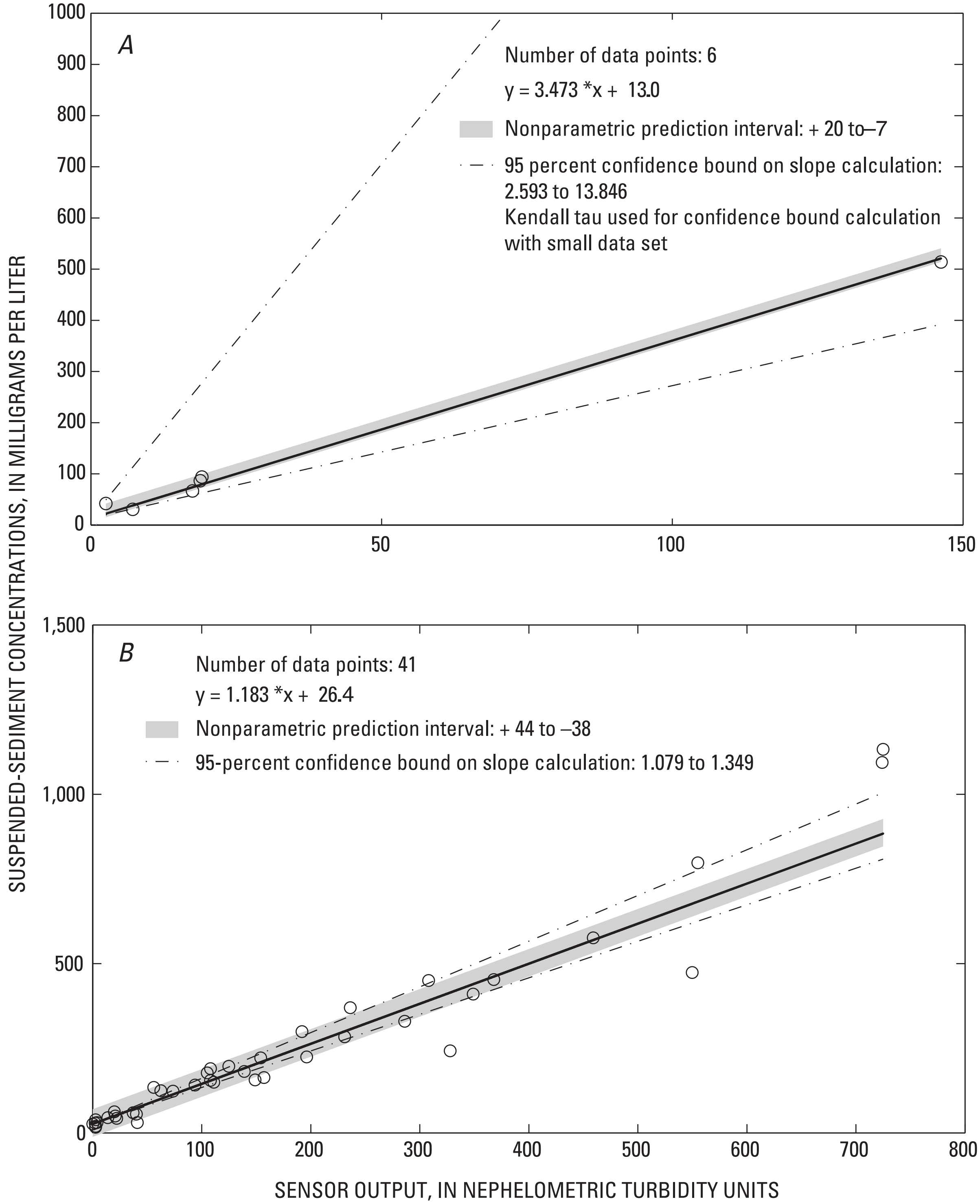

Figure 11. Calibration of near-bottom optical backscatterance sensor, October 1–February 15 (*A*) and February 15–September 30 (*B*) at Channel Marker 9, San Pablo Bay, California, water year 2000.

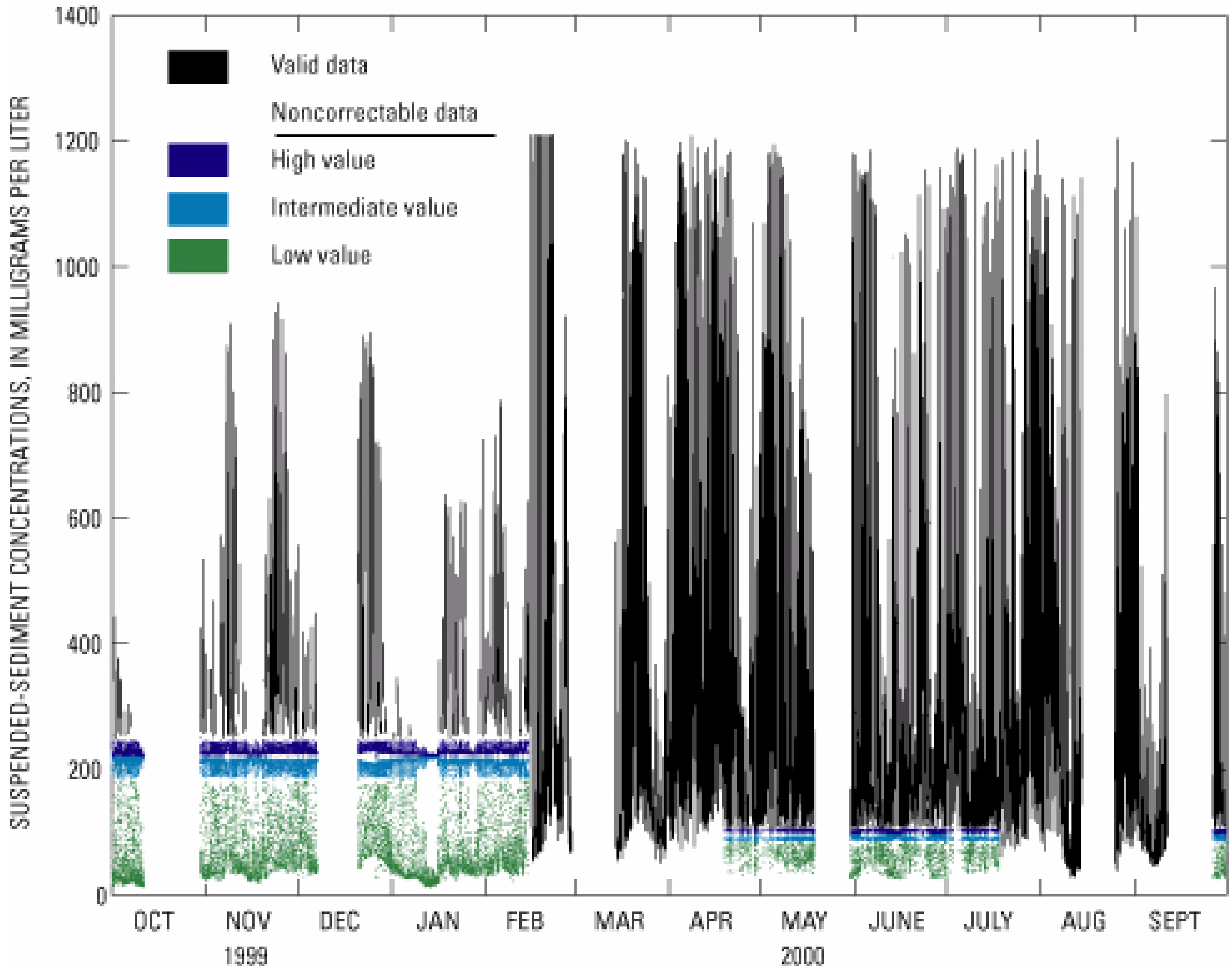

Figure 12. Time series of near-bottom suspended-sediment concentrations calculated from sensor readings at Channel Marker 9, San Pablo Bay, water year 2000.

Central San Francisco Bay

Point San Pablo

The suspension line for the sensors broke on November 11, 1999, and was replaced on November 15, 1999. The calibration of the mid-depth sensor was developed using 103 water samples collected from August 15, 1995, through water year 2000 (fig. 13*A*). The calibration of the near-bottom sensor was developed using 131 water samples collected from August 15, 1995, through water year 2000 (fig. 13*B*). Suspended-sediment concentration data collected during water year 2000 are presented in figure 14.

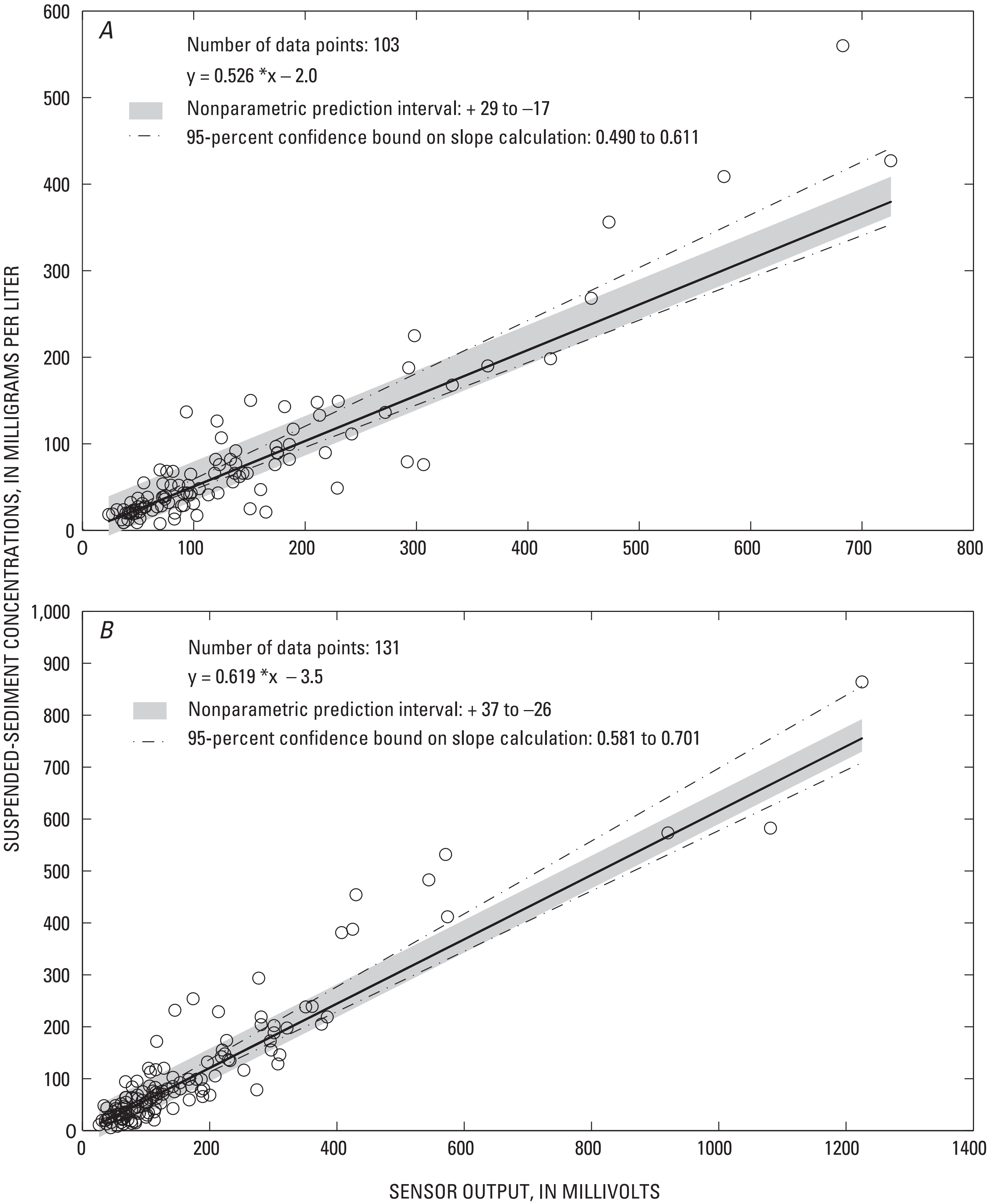

Figure 13. Calibration of mid-depth (*A*) and near-bottom (*B*) optical backscatterance sensors at Point San Pablo, Central San Francisco Bay, California, water year 1999.

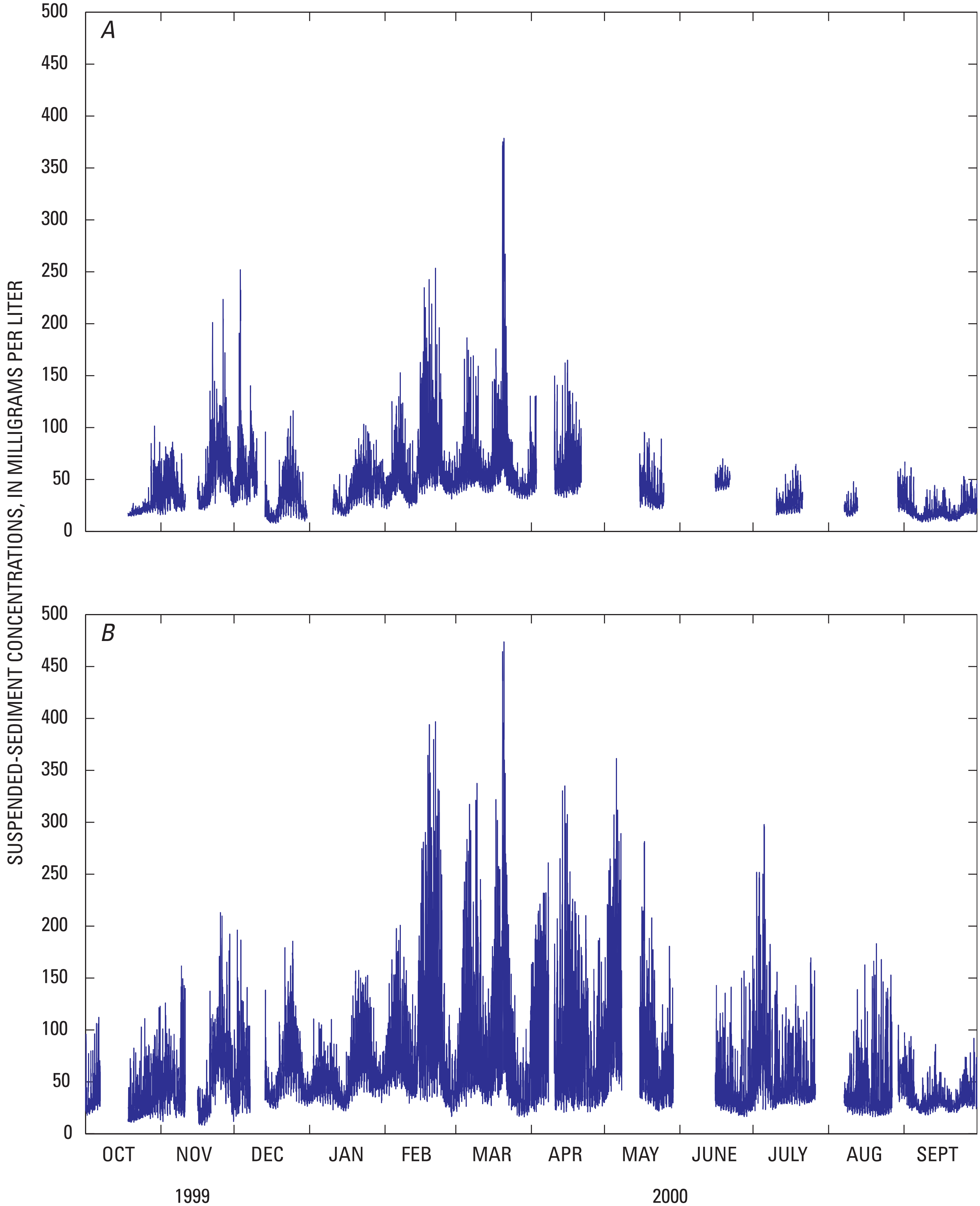

Figure 14. Time series of mid-depth (*A*) and near-bottom (*B*) suspended-sediment concentrations calculated from sensor readings at Point San Pablo, Central San Francisco Bay, California, water year 2000.

Pier 24

The suspension line for the sensors broke on September 26, and was replaced on October 4, 2000. Calibration of the mid-depth sensor was developed from 37 water samples collected from May 20, 1998, through water year 2000 (fig. 15*A*). On June 14, 2000, the lower sensor cable was found damaged and was replaced. Calibration of the near-bottom sensor was developed from 97 water samples collected from June 22, 1995, through water year 2000 (fig. 15*B*). Suspended-sediment concentration data collected during water year 2000 are presented in figure 16.

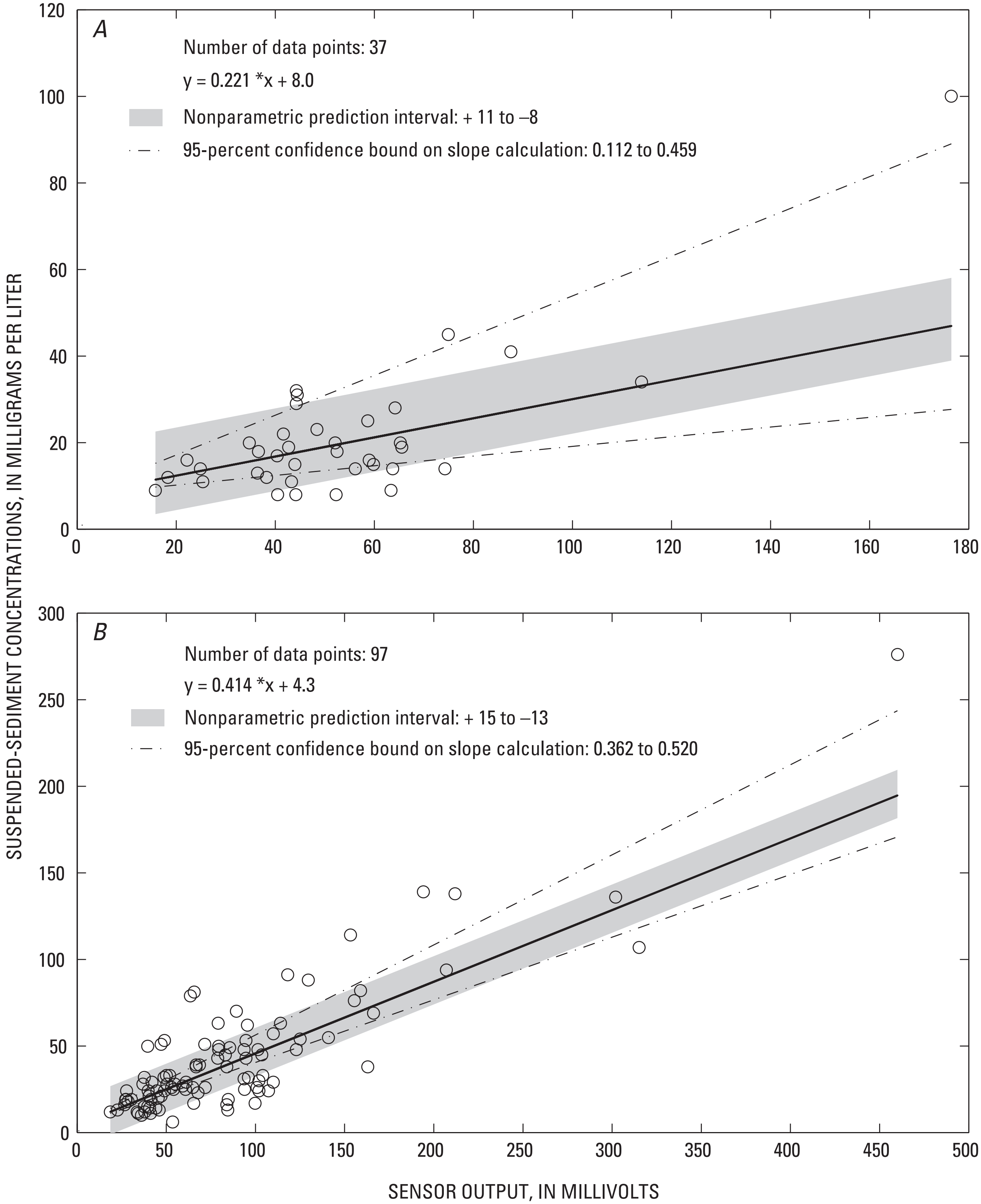

Figure 15. Calibration of mid-depth (*A*) and near-bottom (*B*) optical backscatterance sensors at Pier 24, Central San Francisco Bay, California, water year 2000.

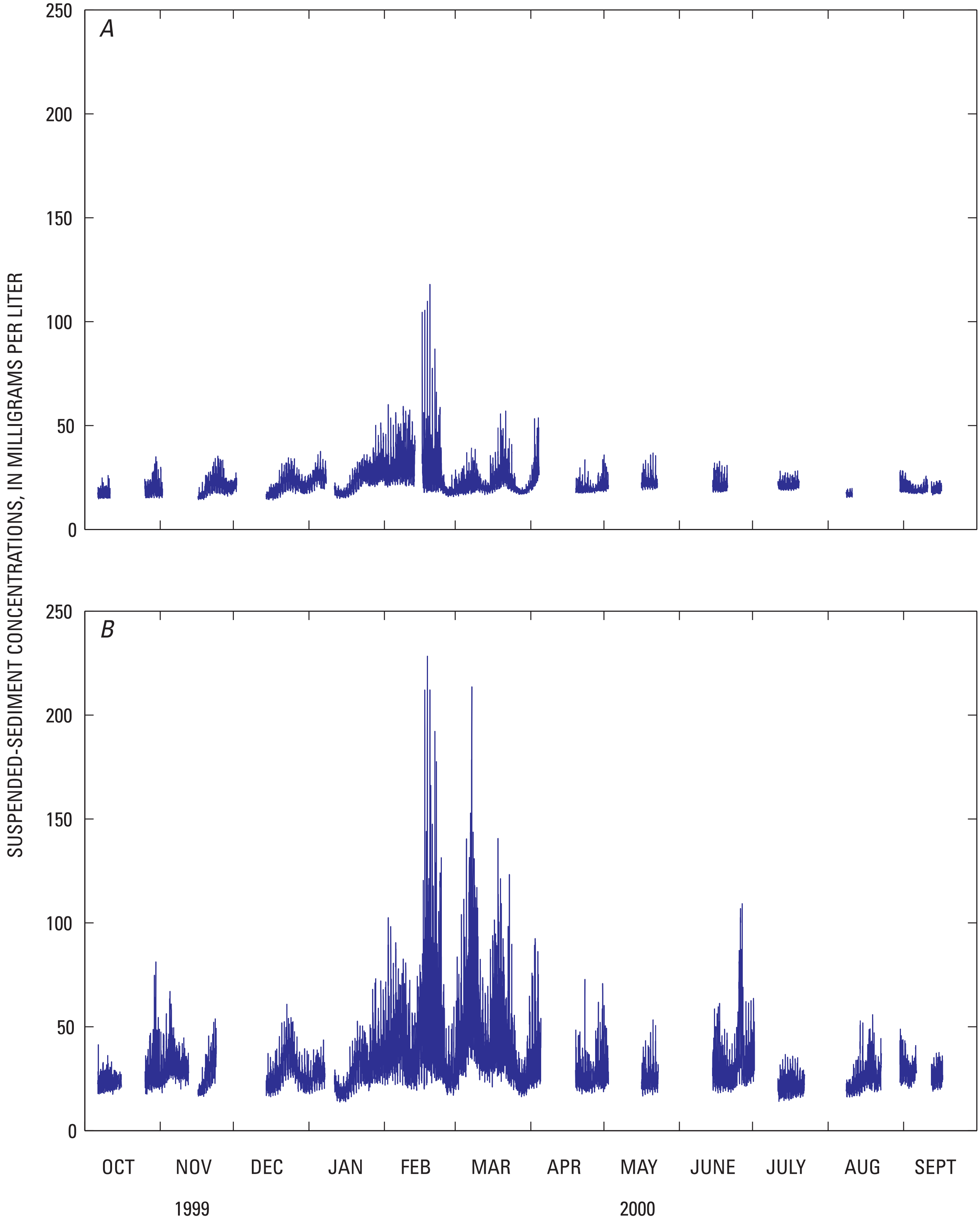

Figure 16. Time series of mid-depth (*A*) and near-bottom (*B*) suspended-sediment concentrations calculated from sensor readings at Pier 24, Central San Francisco Bay, California, water year 2000.

South San Francisco Bay

San Mateo Bridge

The station was reestablished on June 14, 2000, after completion of the seismic retrofitting of the San Mateo Bridge. The mid-depth sensor cable was damaged in late June 2000 and was replaced on August 9, 2000. The battery regulator blew a fuse and the battery eventually lost power resulting in lost data from August 5 to August 9, 2000. The calibration of the mid-depth sensor was developed from 40 water samples collected from March 13, 1997, through water year 2000 (fig. 17*A*). The calibration of the near-bottom sensor was developed from 19 water samples collected from January 12, 1999, to June 6, 2001 (water year 2001 samples were used to help develop the calibration) (fig. 17*B)*. Suspended-sediment concentration data collected during water year 2000 are presented in figure 18.

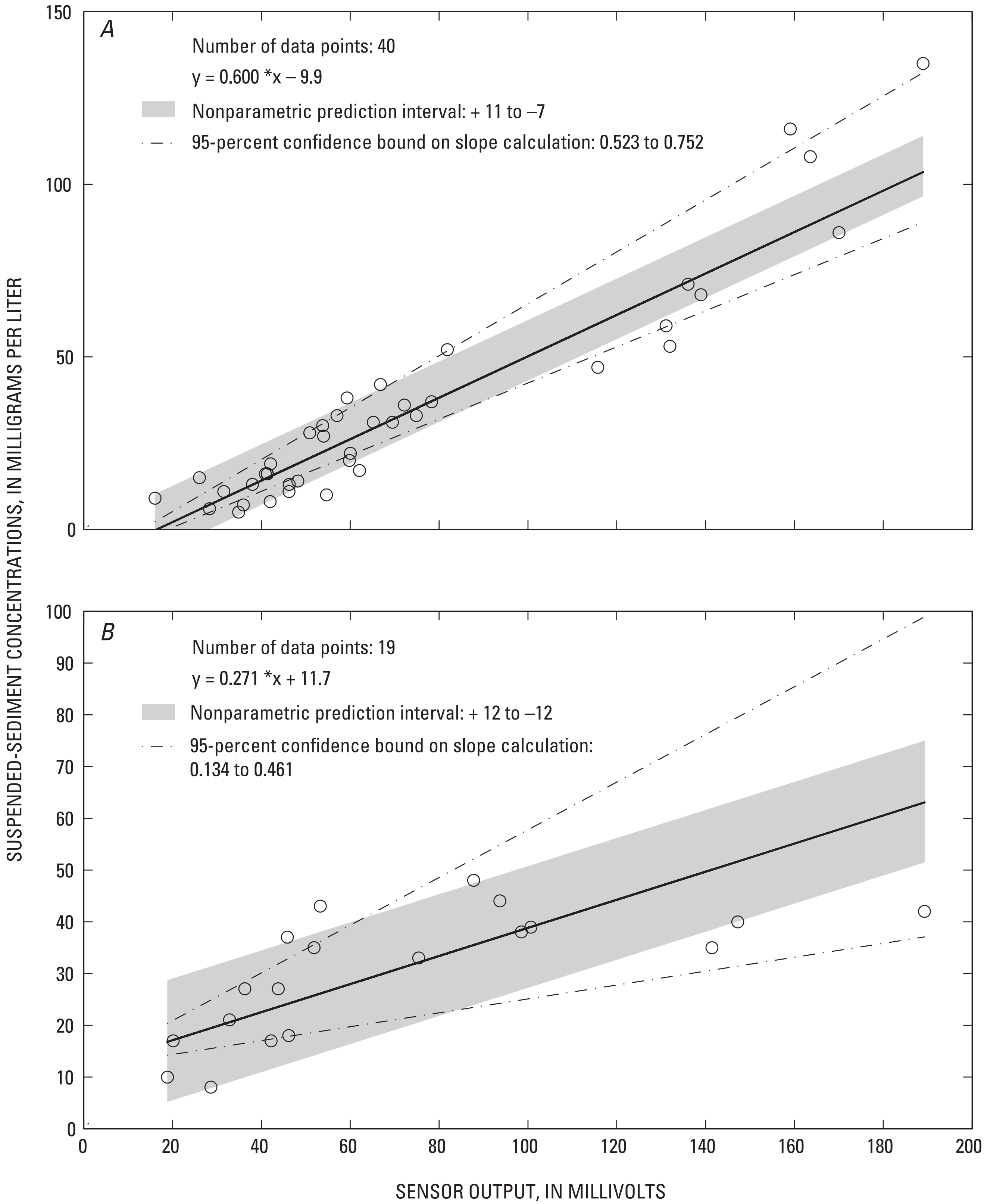

Figure 17. Calibration of mid-depth (*A*) and near-bottom (*B*) optical backscatterance sensors at San Mateo Bridge, South San Francisco Bay, California, water year 2000.

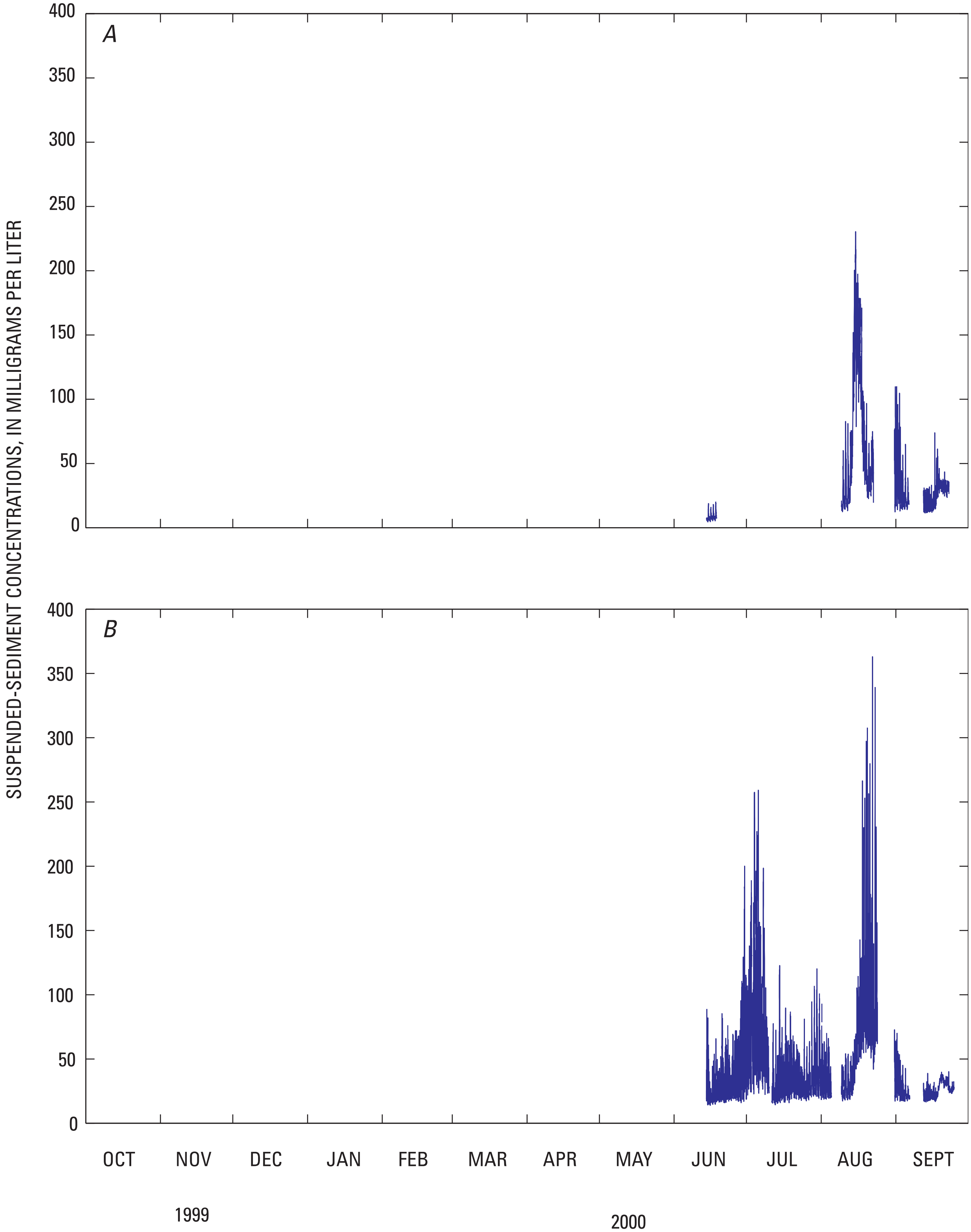

Figure 18. Time series of mid-depth (*A*) and near-bottom (*B*) suspended-sediment concentrations calculated from sensor readings at San Mateo Bridge, South San Francisco Bay, California, water year 2000.

Dumbarton Bridge

The analysis of water samples collected in water years 2000 and 2001 showed that the electrical output of the mid-depth sensor, in operation since June 18, 1996, had drifted with time. The calibration of the mid-depth sensor was developed from 24 water samples collected from October 5, 1999, to May 16, 2001 (fig. 19*A*). The calibration of the near-bottom sensor was developed from 35 water samples collected from October 7, 1998, through water year 2000 (fig. 19*B*). Suspended-sediment concentration data collected during water year 2000 are presented in figure 20.

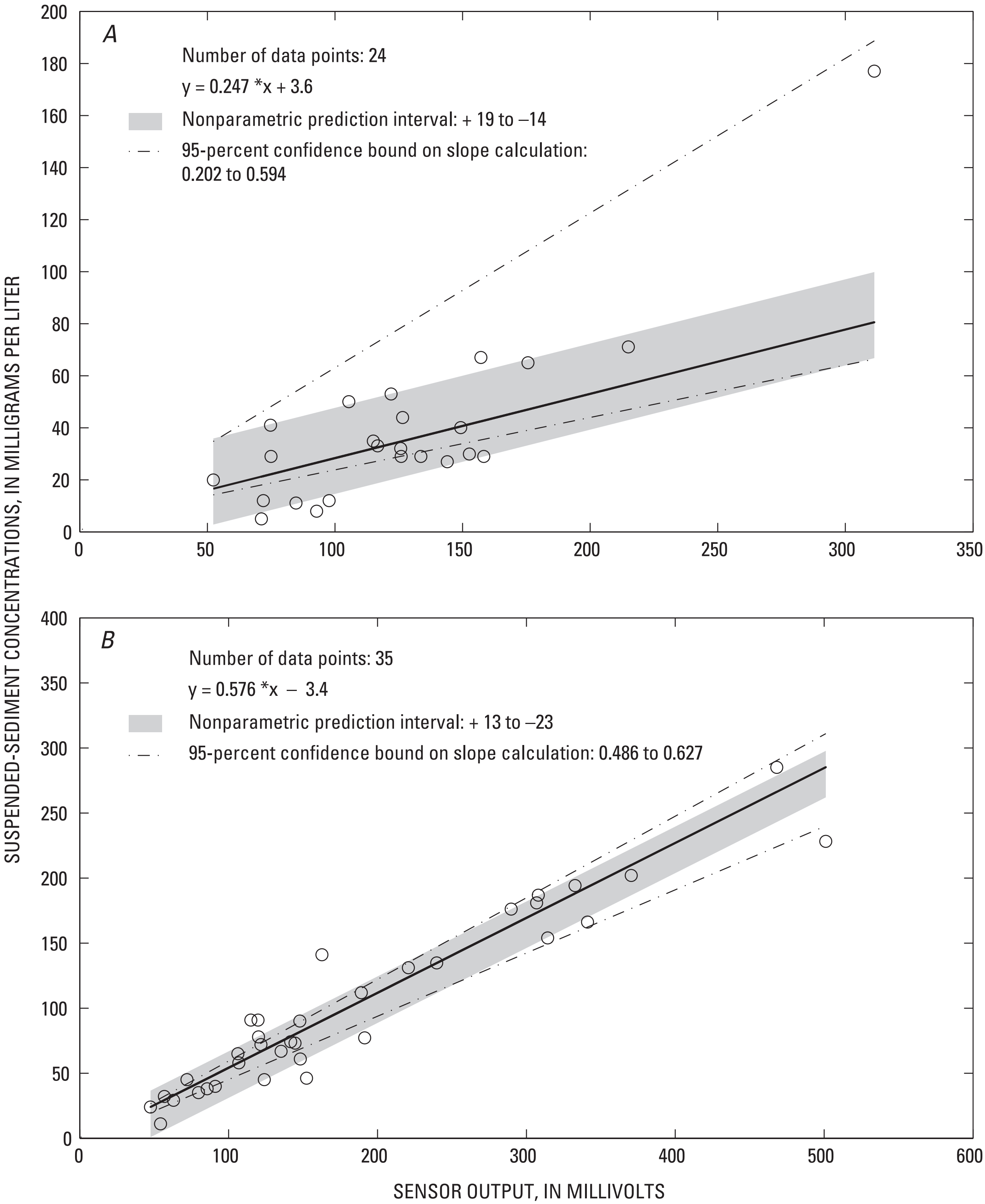

Figure 19. Calibration of mid-depth (*A*) and near-bottom (*B*) optical backscatterance sensors at Dumbarton Bridge, South San Francisco Bay, California, water year 2000.

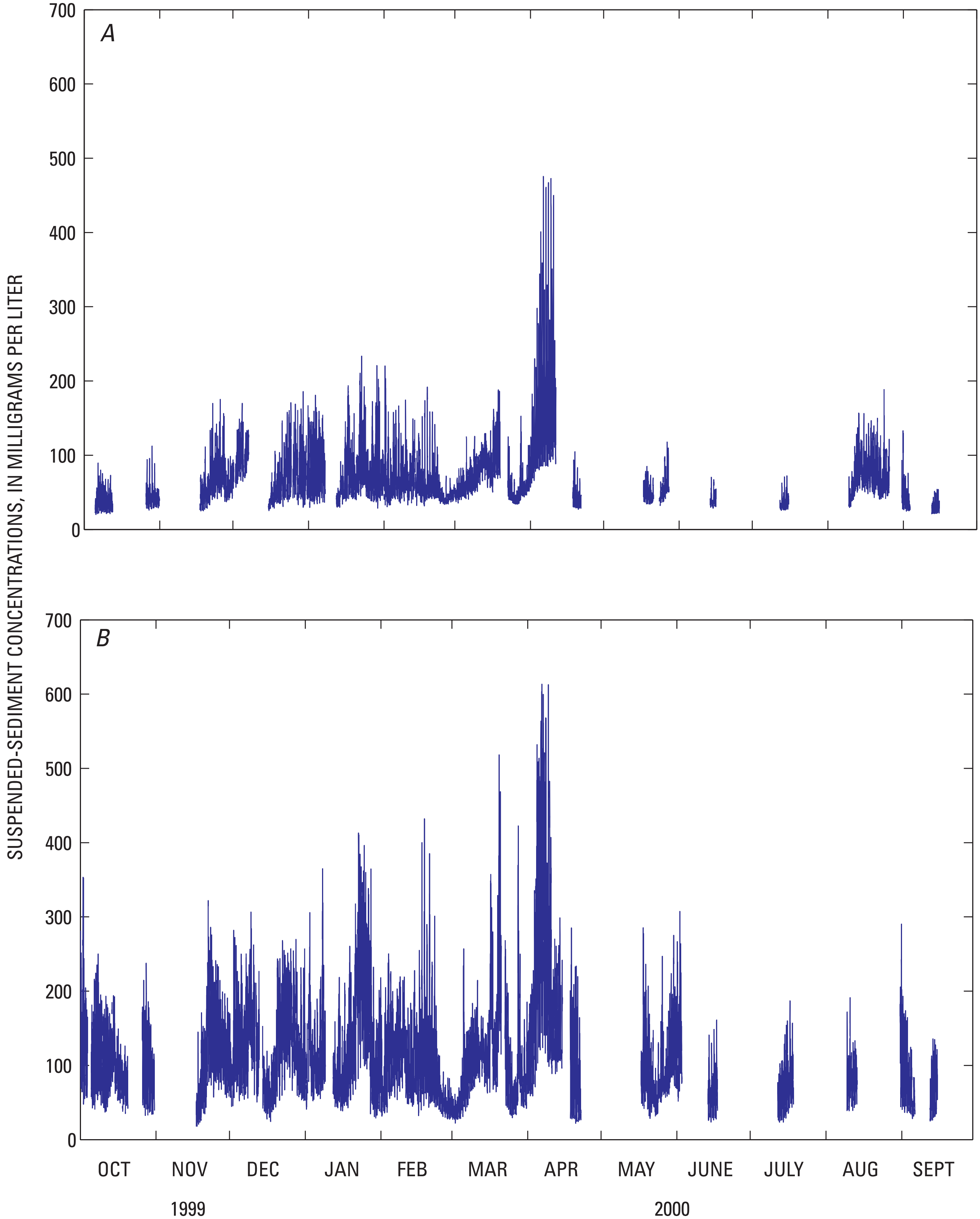

Figure 20. Time series of mid-depth (*A*) and near-bottom (*B*) suspended-sediment concentrations calculated from sensor readings at Dumbarton Bridge, South San Francisco Bay, California, water year 2000.

Channel Marker 17

The calibration of the mid-depth sensor was developed from 63 water samples collected from February 26, 1997, through water year 2000 (fig. 21*A*). The calibration of the near-bottom sensor was developed from 41 water samples collected from July 30, 1998, through water year 2000 (fig. 21*B*). Suspended-sediment concentration data collected during water year 2000 are presented in figure 22.

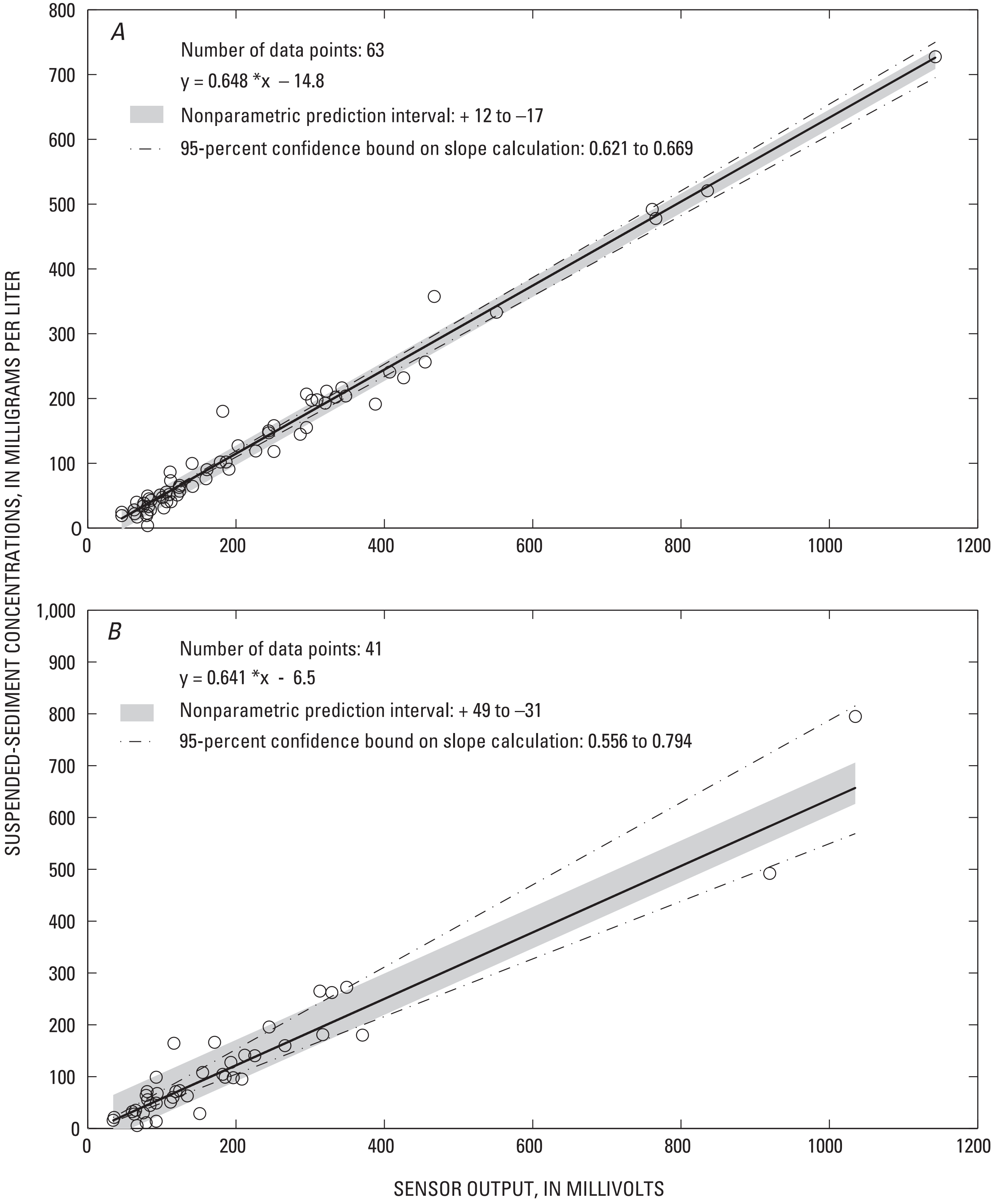

Figure 21. Calibration of mid-depth (*A*) and near-bottom (*B*) optical backscatterance sensors at Channel Marker 17, South San Francisco Bay, California, water year 2000.

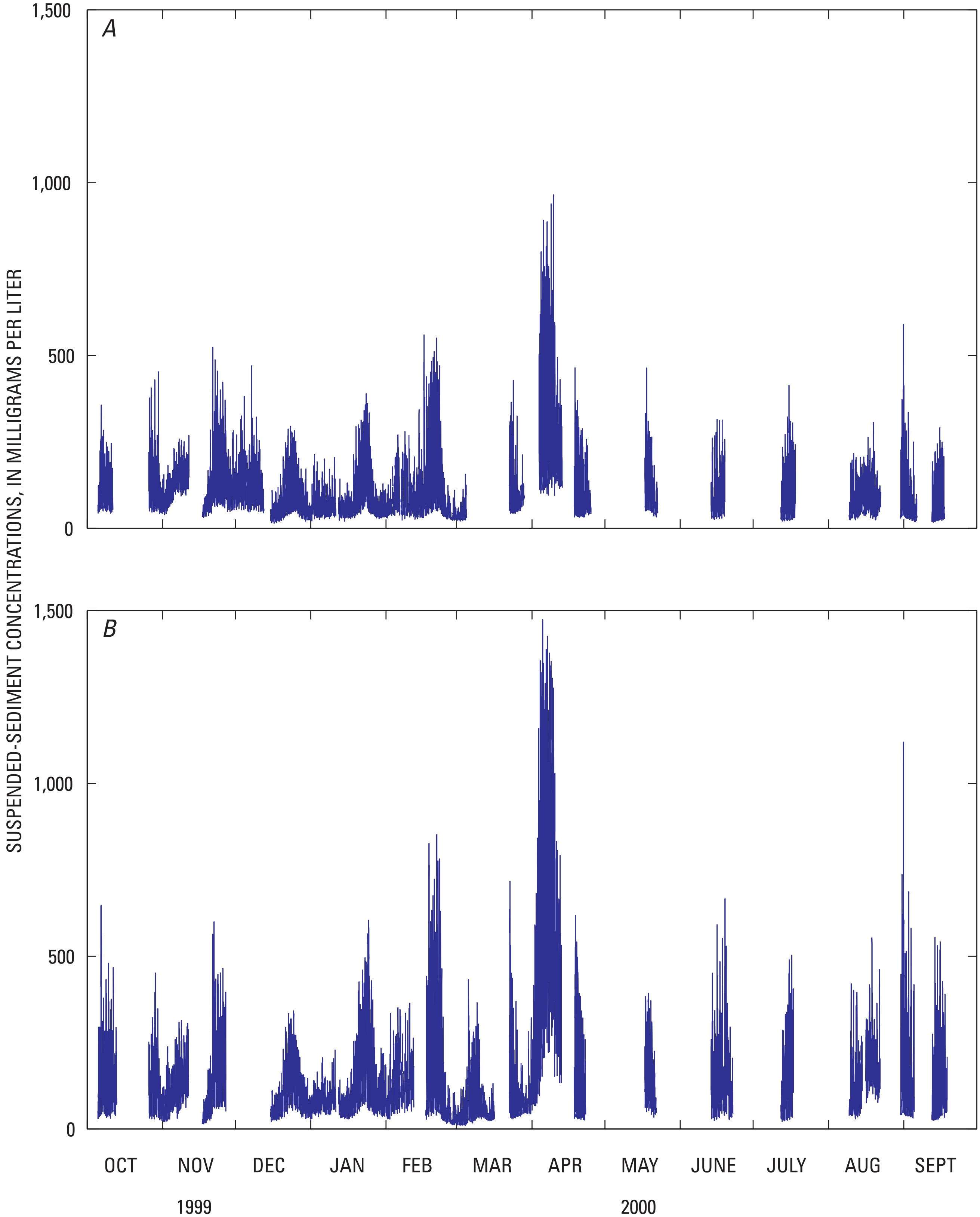

Figure 22. Time series of mid-depth (*A*) and near-bottom (*B*) suspended-sediment concentrations calculated from sensor readings at Channel Marker 17, South San Francisco Bay, California, water year 2000.

SUMMARY

Suspended-sediment concentration data were collected by the U.S. Geological Survey (USGS) at one site in Suisun Bay, three sites in San Pablo Bay, two sites in Central San Francisco Bay, and three sites in South San Francisco Bay during water year 2000. Three types of optical backscatterance sensors, controlled by an electronic data logger, were used to monitor suspended sediment. Water samples were collected to calibrate the electrical output of the optical sensors to suspended-sediment concentration, and the recorded data were recovered and edited. Suspended-sediment concentration data are available from the USGS in Sacramento, California.

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